Pre-Landing Site Workshop 3 Engineering Assessment Telecon

Mars 2020

January 31, 2017

Overview

- The 3rd Landing Site Workshop for the Mars 2020 mission will be on February 8-10, in Monrovia, CA.
- To allow the workshop to focus on science assessment of the candidate landing sites, engineering presentations from the project team will be kept to a minimum
- This engineering telecon is intended to expose the science community to:
  - The methods used for assessing the landing sites
  - The maturity of the engineering assessment
  - Summary results for the candidate sites
- Although certain sites present significant challenges in achieving the full mission objectives, no sites present unacceptable risk
- Project recommends downselecting landing sites based on science value

Agenda

	Topic	Presenter	Start Time	Duration
1	Introduction	Chen	10:00 AM	5
2	Landing Safety Assessment			
2-1	Atmosphere	Villar	10:05 AM	15
2-2	Terrain	Otero	10:20 AM	25
3	Surface Assessment			
3-1	Traversability	Ono	10:45 AM	30
3-2	Mission Performance	Lange	11:15 AM	15
4	Wrap Up and Questions	Chen	11:30 AM	15

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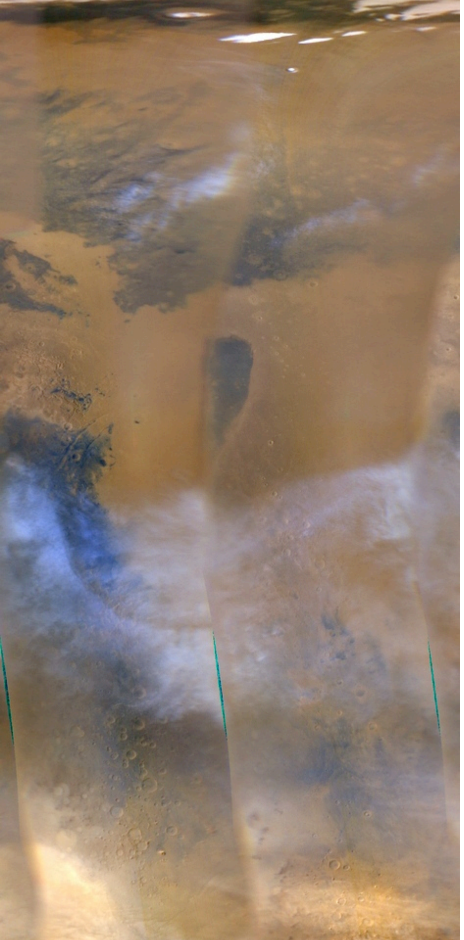
Landing Safety Assessment

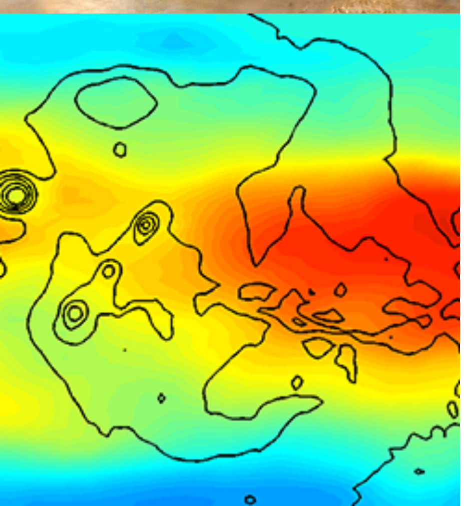
EDL Design Team

January 31, 2017

EDL Overview

- Since the last landing site workshop in August 2015, TRN has been added to the EDL baseline
- When combined with range trigger, TRN gives the system a significant improvement in landing site accessibility
- Atmosphere and terrain characterization efforts have matured and are on par with the maturity MSL had at final site selection
- All candidate landing site can be reached with acceptable risk
  - However, the team has less confidence in its assessment for one site





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Atmosphere Assessment

Presented by Gregory Villar
on behalf of the Council of Atmospheres

Mars 2020 Landing Site Engineering Teleconference
January 31, 2017

Pre-decisional: For Planning and Discussion Purposes Only

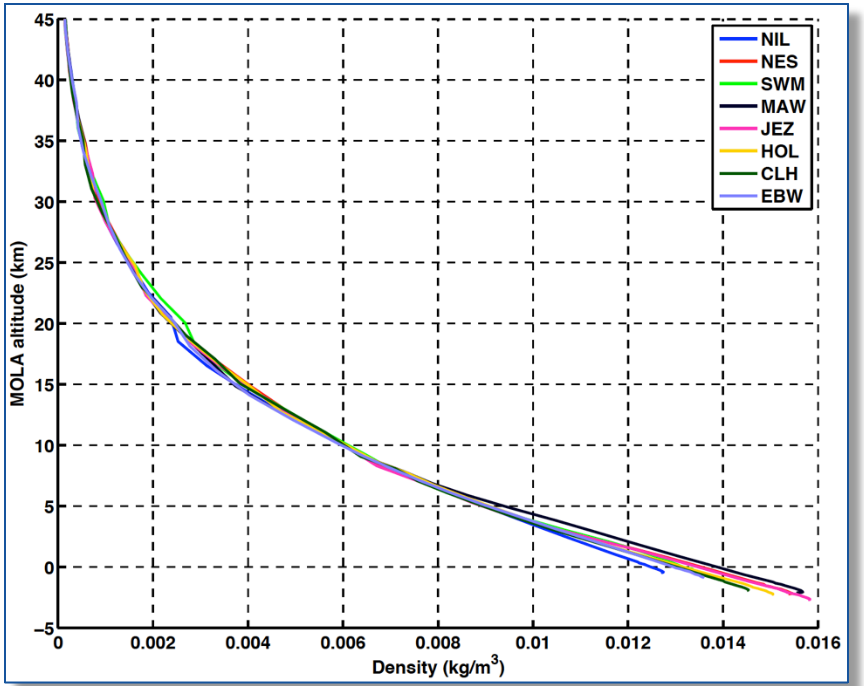
Work Since LSW2

- Ran mesoscale models for new sites emerging from LSW2
  - Eberswalde
  - Colombia Hills
- Ran mesoscale dust storm scenarios for Syrtis region sites
  - Nili Fossae (ran through EDL simulations)
  - Jezero
  - North East Syrtis
- Generated dust storm statistics for Top 8 sites
- Delivered assessment of nominal atmosphere for LSW3 sites

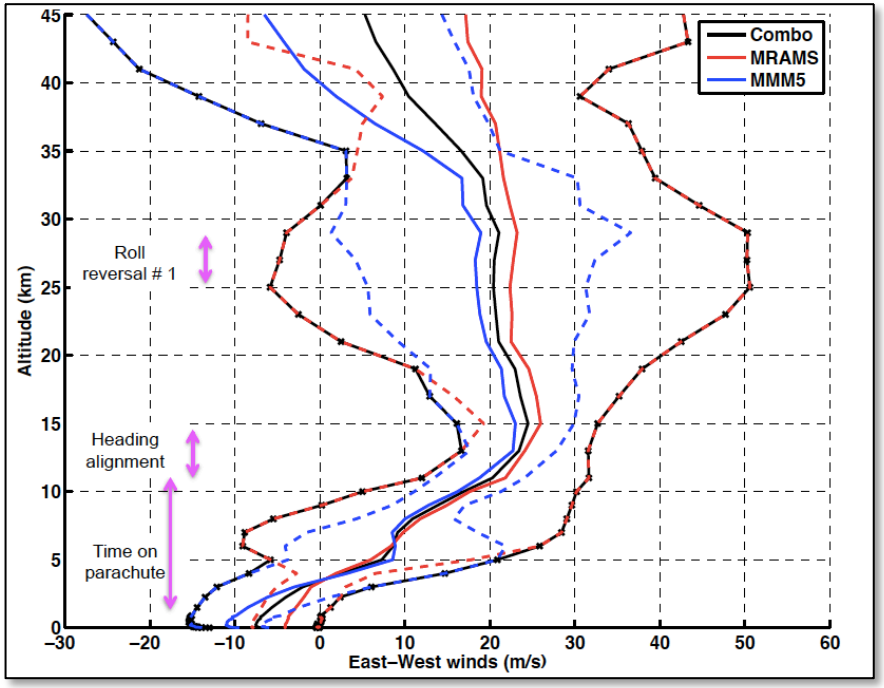
Current Mars 2020 CoA status is more mature than MSL at final site selection

Mesoscale Model Outputs

- Primary outputs considered in EDL performance
  - Density (>30km) – contributes to experienced loads and entry guidance performance
  - Winds (<30km) – most influential on ellipse size from parachute deploy to touchdown



Density at Candidate Sites



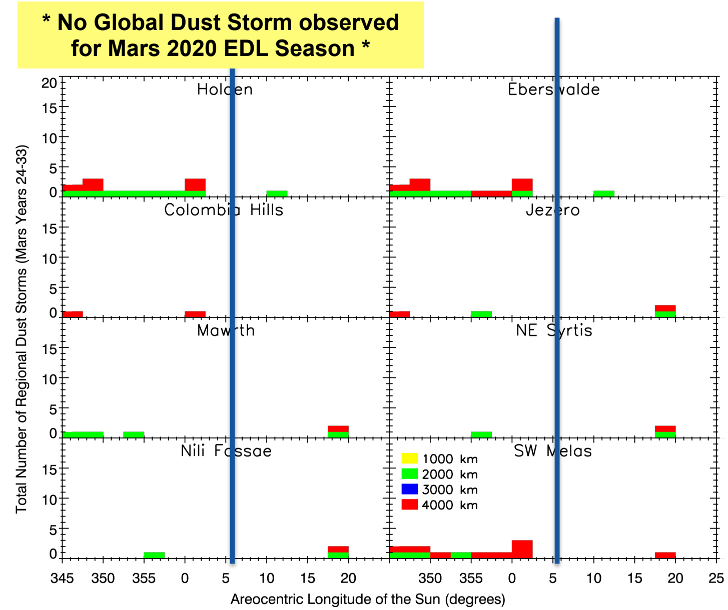
Example of Mesoscale Products

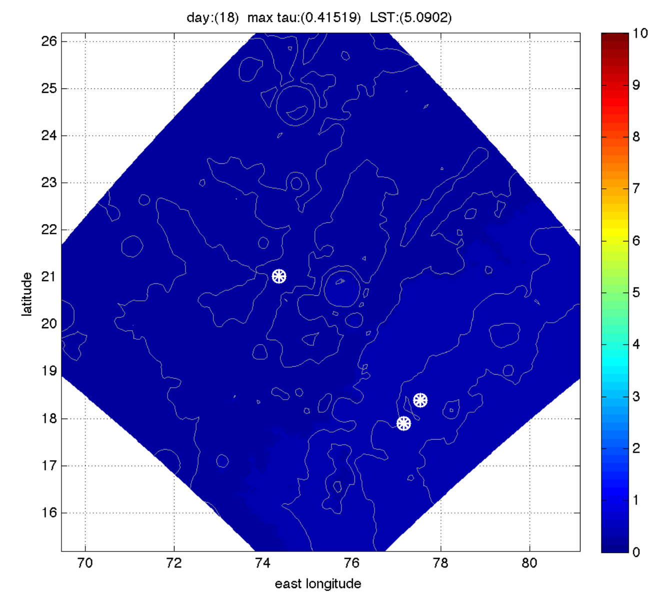
North East Syrtis – East-West Winds

Plot Credit: Dutta

Dust Considerations

- Very low likelihood of dust event for Mars 2020 EDL
  - However, Mars 2020 CoA still practiced due diligence
- Dust scenario mesoscale data generated for Syrtis region sites
  - North East Syrtis
  - Jezero
  - Nili Fossae
- Ran North East Syrtis dust storm mesoscale data through EDL performance simulation
  - Results show EDL system robust to dust





CoA Assessment of Top 8 Sites

Site	Atmosphere	Comments
Colombia Hills		• Moderate differences between models
Eberswalde		
Holden		
Jezero		
Mawrth		• Slight differences between models • EDL can tolerate more uncertainty at this site
North East Syrtis		
Nili Fossae		
South West Melas		• Noticeable difference in wind profiles between models • Challenging to model this site, i.e. low confidence • Ellipse is placed in tight area • If ellipse was in larger area, then EDL can tolerate more uncertainty

Acceptable EDL performance at Top 8 sites using nominal atmospheres

Will further investigate SWM, MAW, CLH if still considered after LSW3

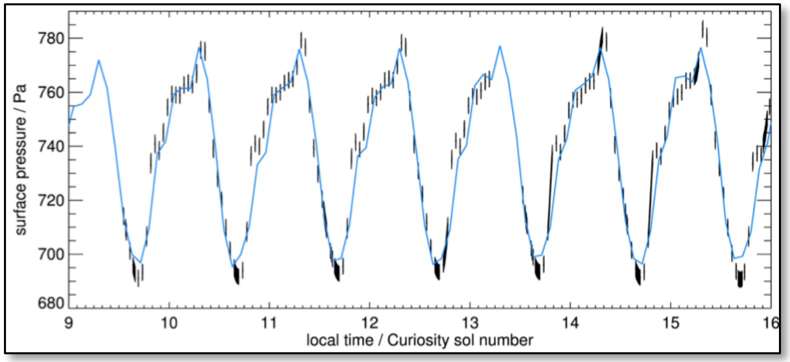
Future Work

- **Atmosphere Characterization Independent Peer Review**
  - April 26, 2017

- **Dust Characterization**
  - Provide areal extent and column opacity of regional dust storms
  - Retrieve column dust opacity of local dust storms
  - Generate full-year dust storm survey at final selected site

- **Surface Pressure Estimates**
  - Use predicted surface pressures to normalize mesoscale models
  - Validate surfaces pressure estimates using radio science

Plot Credit: Lewis & Hinson



Curiosity Surface Pressure Prediction vs. Data

Current Mars 2020 CoA status is more mature than MSL at final site selection

Terrain Assessment

Council of Terrains

Landing Sites Analyzed

- Trajectory Monte Carlos using mesoscale atmospheres and system performance uncertainty models inform ellipse sizes
- Ellipse placements balance landed safety (primary concern) and traverse considerations

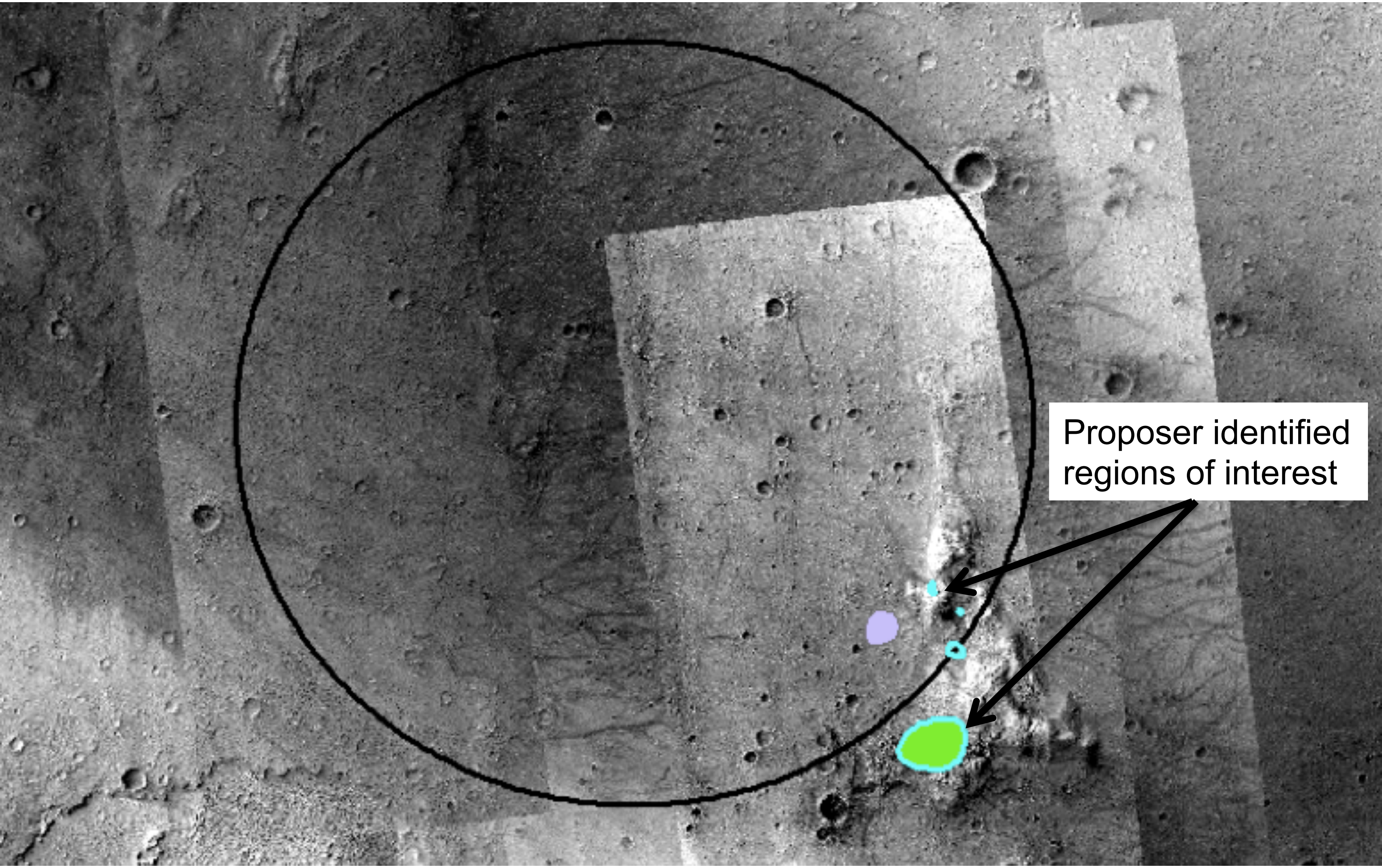
Landing Site	Lat (degN)	Long (degE)	Approx Elevation (km)	Approx Buffered Ellipse Axes (km)
Columbia Hills	-14.5510	175.4527	-1.95	9.6 x 8.7
Eberswalde	-23.7749	-33.5147	-1.49	8.6 x 7.7
Holden	-26.6130	-34.8167	-2.18	9.5 x 8.1
Jezero	18.4386	77.5031	-2.64	10.7 x 8.3
Mawrth	23.9685	-19.0609	-2.24	11.9 x 9.8
NE Syrtis	17.8899	77.1599	-2.04	11.1 x 8.2
Nili Fossae	21.0297	74.3494	-0.65	9.7 x 7.7
SW Melas	-9.8132	-76.4679	-1.92	9.7 x 8.7

All landing sites achieve landed risk postures in family with MSL

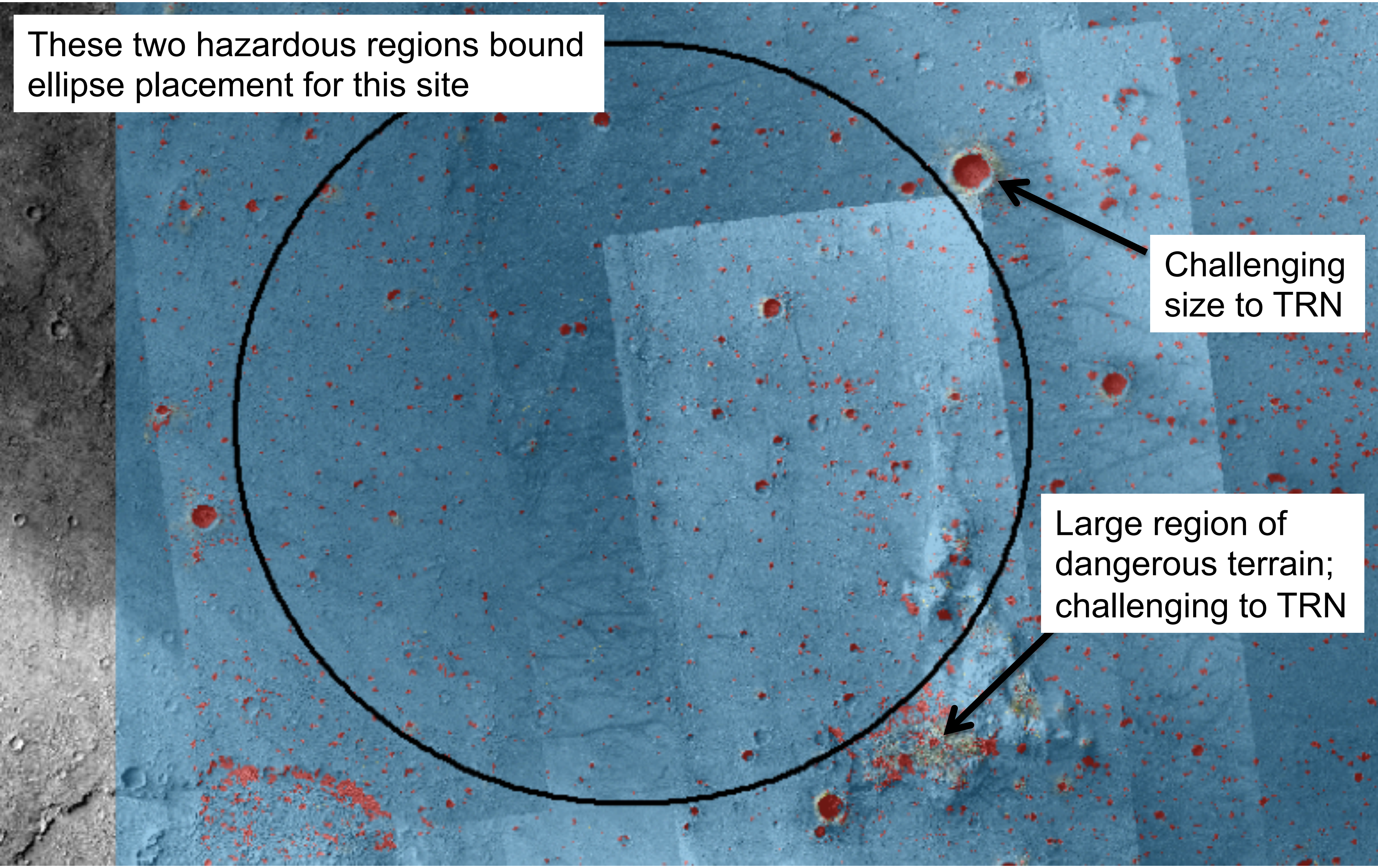
Hazards that were Considered

- Rocks
  - Large dangerous rocks identified through HiRISE imagery and smaller dangerous rocks estimated by analytical models
- High slopes
  - Identified through Digital Elevation Models of the environment
- Inescapable areas
  - Fresh craters with non-traversable boundaries
  - Sand ripples that look very challenging for traversal; identified through HiRISE imagery
- Thruster plume interaction
  - Bounding analysis for interaction risk with the thruster plume when landing on a given slope
- Relief over a 2.5km baseline
  - Topographical relief may require more fuel for a safe landing
  - A fuel budget constrains the amount of relief we can mitigate

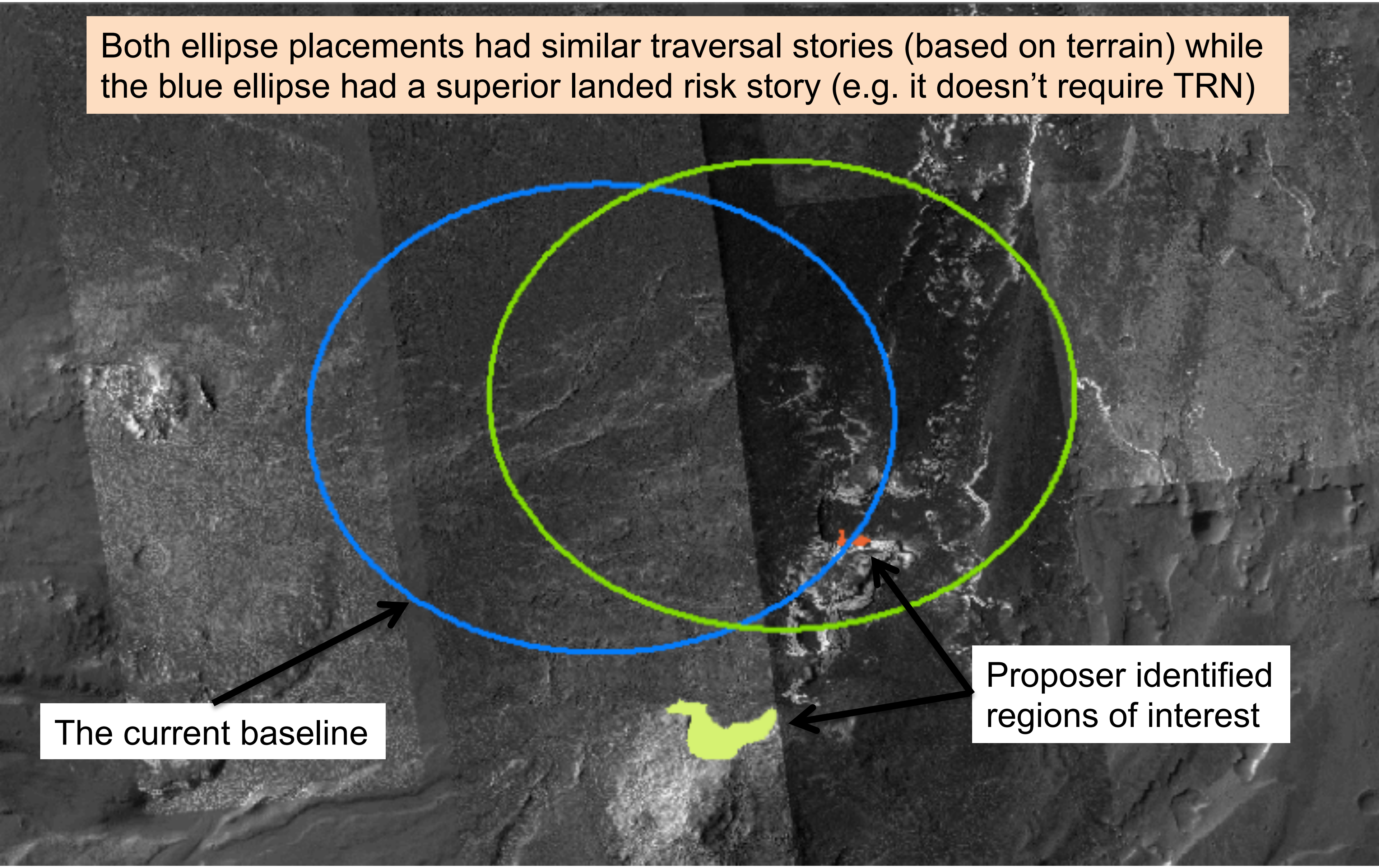
Colombia Hills Ellipse Placement Relative to ROIs



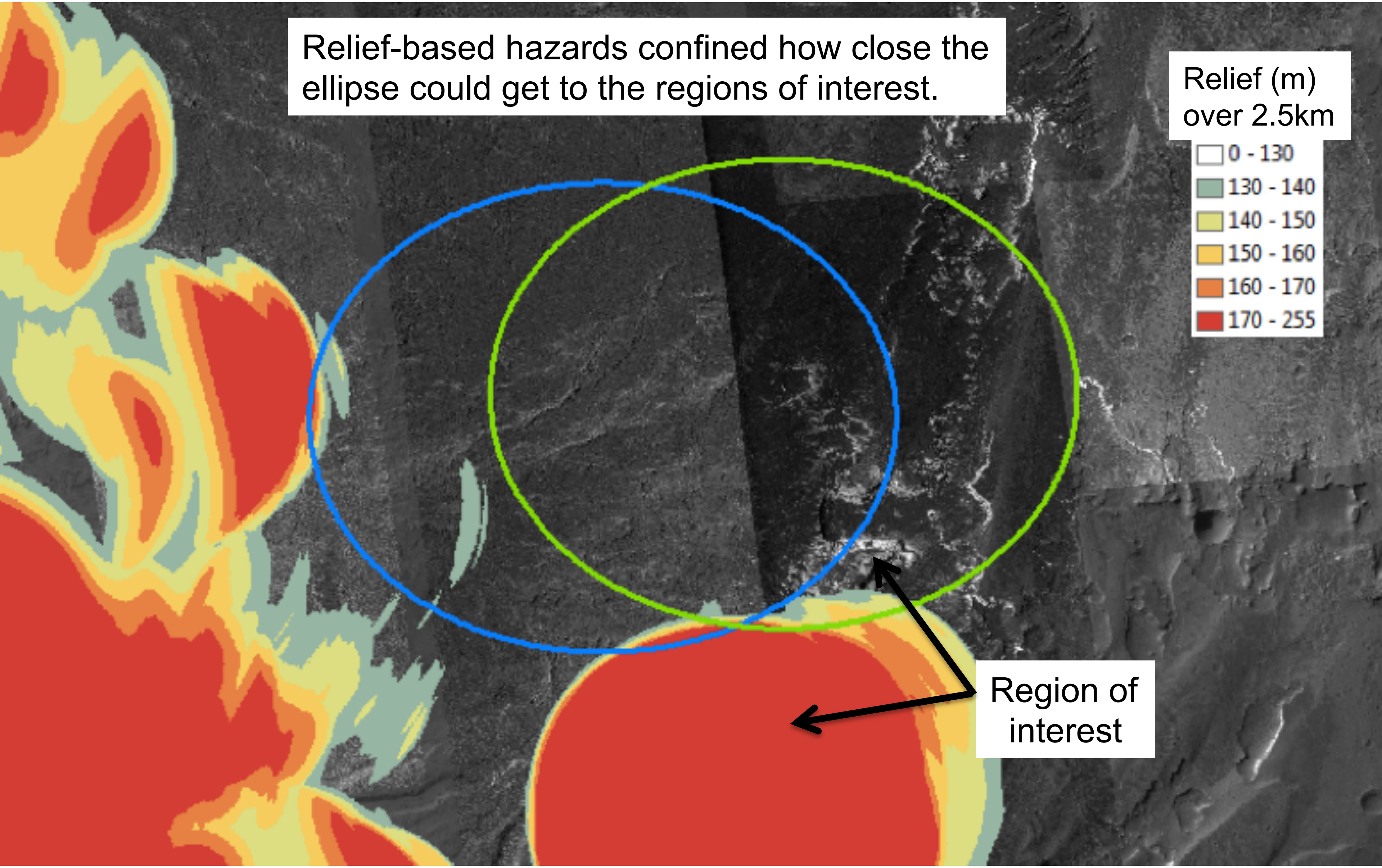
Colombia Hills Hazard Map and Placement Constraints



Holden Ellipse Placement Relative to ROIs



Holden Relief Map and Placement Constraints



Maturity of the Risk Analysis

- All ellipses are well characterized using DEMs, HiRISE images or extrapolated estimates

- No major gaps in terrain knowledge were identified
  - Minor gaps in DEM coverage were examined and their risk was represented using conservative extrapolated slopes

- The risk at these ellipse placements is not expected to fall out of family with MSL
  - Given current atmospheric models
  - Given the current baselined geometry of the rover

- Landing site selection can be driven by the science; EDL can land safely at these locations

Landing Safety Summary

EDL Design Team

EDL Assessment Summary

Site	Atmosphere	Terrain	Overall	Comments
Columbia Hills				Some atmosphere modeling issues identified, but site can tolerate increased ellipse size
Eberswalde				
Holden				
Jezero				
Mawrth				Some atmosphere modeling issues identified, but site can tolerate increased ellipse size
NE Syrtis				
Nili Fossae				
SW Melas				Lack of confidence in atmosphere modeling results coupled with significant terrain hazards bordering the landing ellipse raise concerns

All candidate landing sites are accessible with acceptable risk

Atmosphere modeling issues and tight ellipse placement at SW Melas will present challenges going forward

Surface Assessment

Surface Design Team

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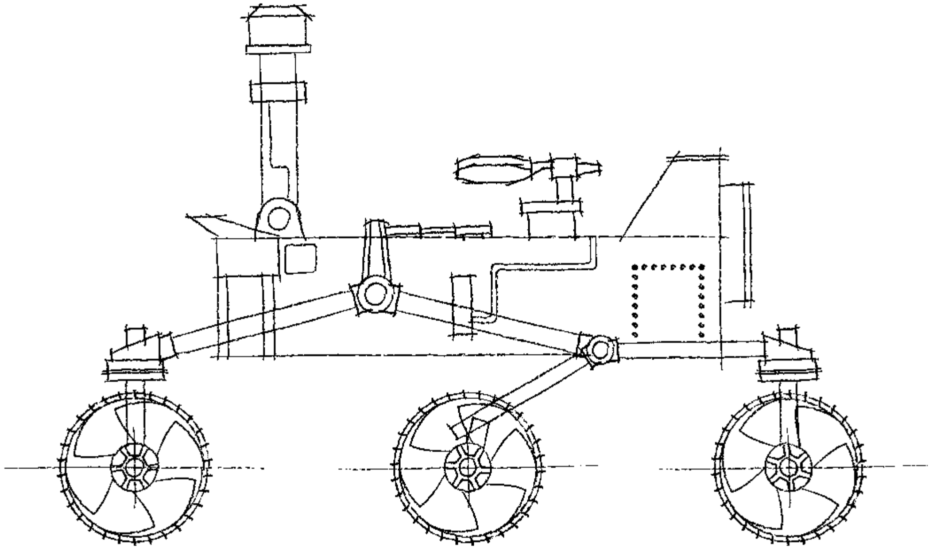
Landing Site Traversability

Pre-LSW3 Engineering Briefing

Hiro Ono
January 31, 2017



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Acknowledgements

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- Austin Nicholas
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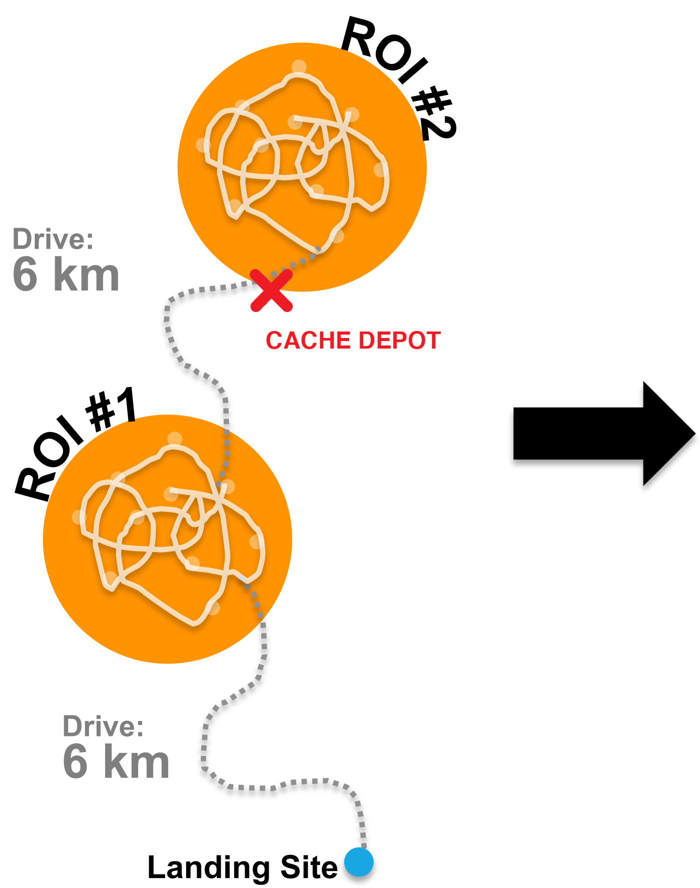
- Richard Otero
- Ken Williford
- Matt Golombek
- Rob Lange
- Sarah Milkovich
- Rich Rieber

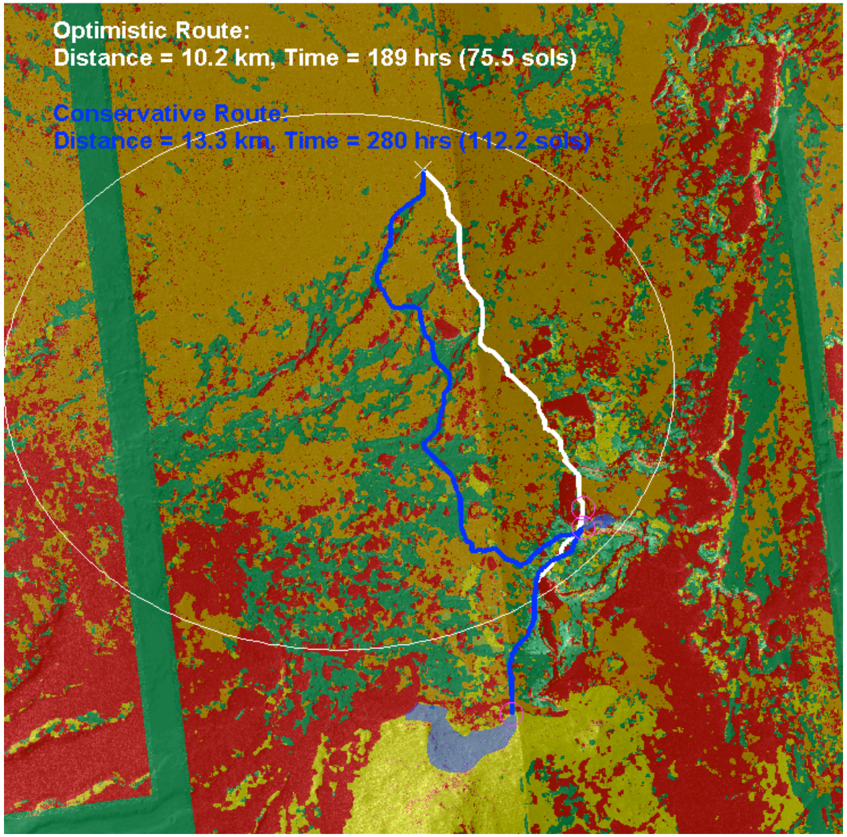
Site Proposers

- Steve Ruff (CLH)
- Melissa Rice (EBW)
- Sanjeev Gupta (EBW)
- Nick Warner (EBW)
- Ross Irwin (HOL)
- James Wray (HOL)
- John Grant (HOL)
- Jack Mustard (JEZ, NES, NIL)
- Bethany Ehlmann (JEZ, NES)
- Tim Goudge (JEZ)
- Briony Horgan (MAW)
- Damien Loizeau (MAW)
- Francois Poulet (MAW)
- Michael Bramble (NES)
- Kevin Cannon (NIL)
- Becky Williams (SWM)

Landing Site Specific Analysis

Attempting to move from a generic Baseline Reference Scenario (BRS) to analyzing a specific mission at each landing site



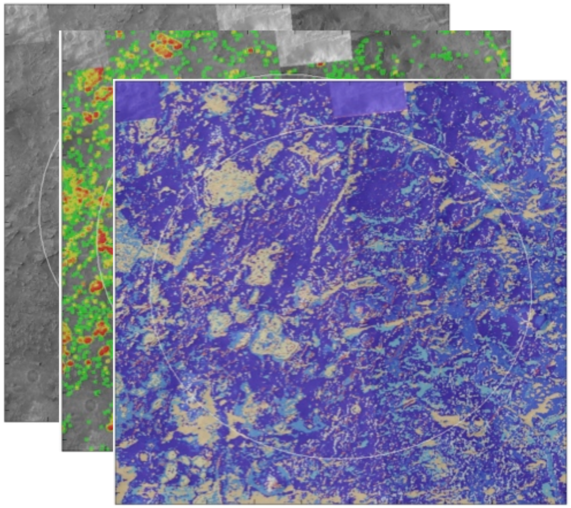


Example scenario at Holden Crater

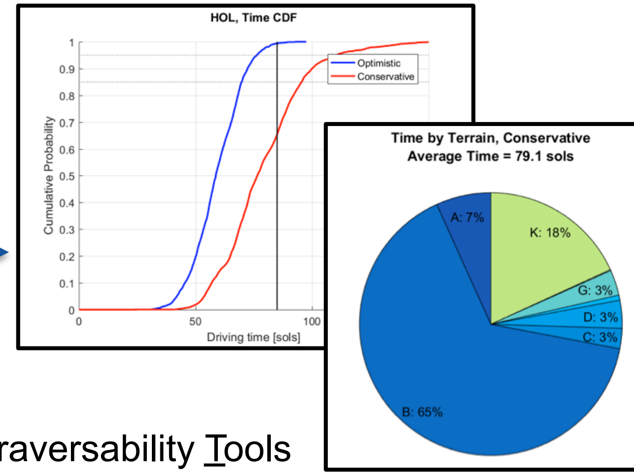
Data-driven Traversability Analysis

Inputs: slope, CFA, terrain type

Output: Statistics of time/distance



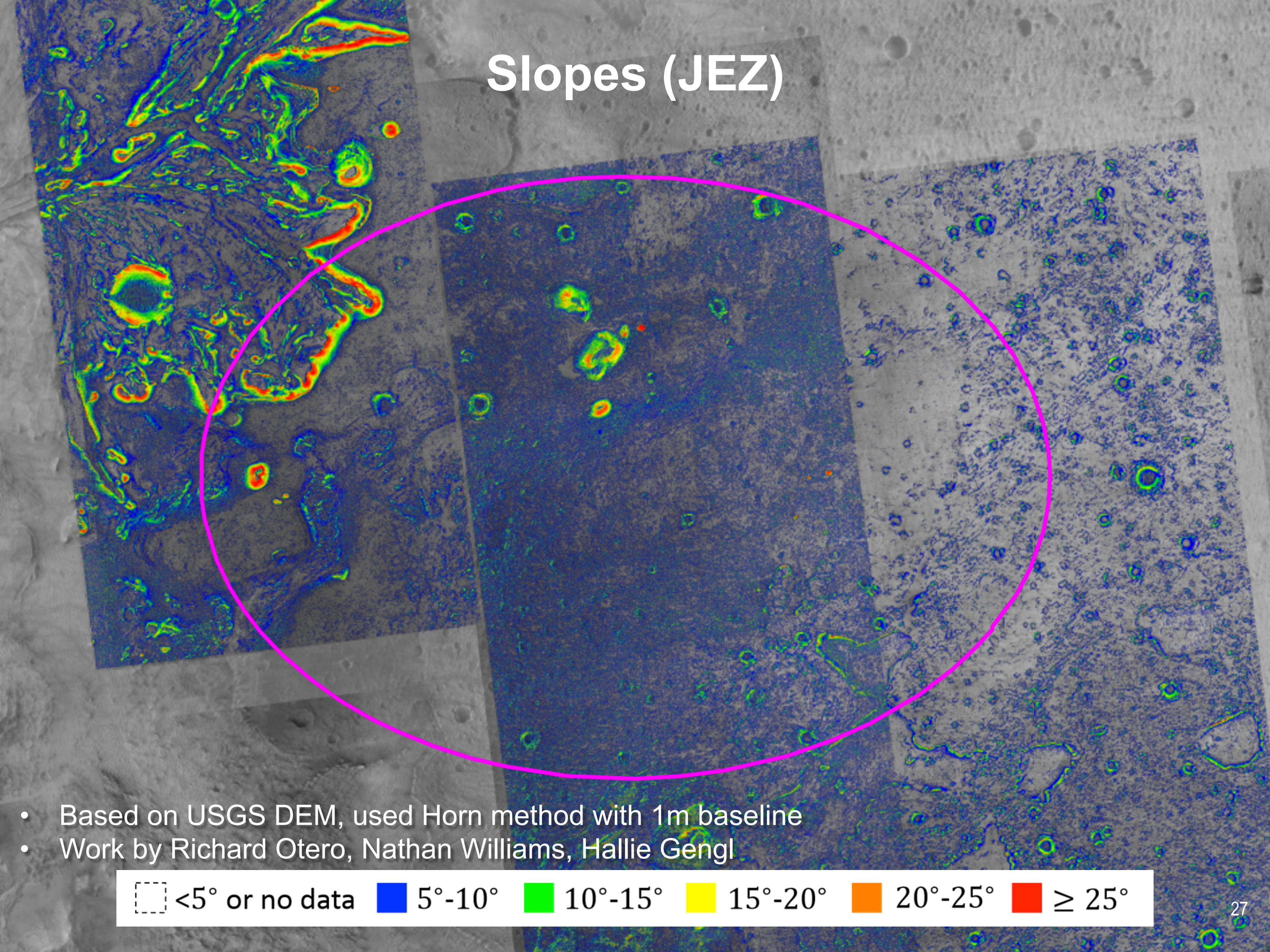
MTTT



MTTT = Mars Twenty-twenty Traversability Tools

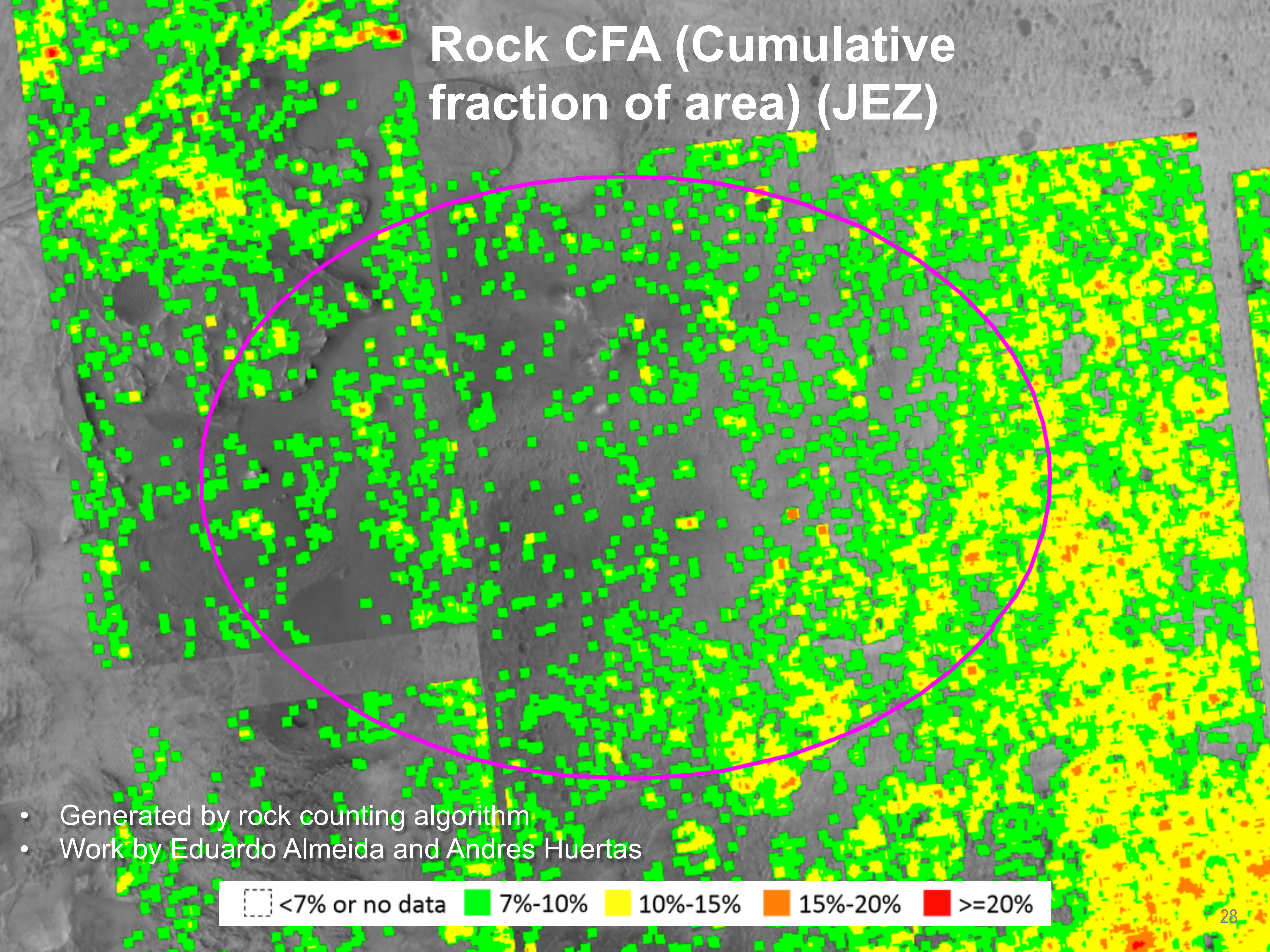
- Uses slope, CFA, and terrain type to assess traversability (MSL did not use terrain classification)
- Outputs statistical distribution of driving time and distance to visit required ROIs
- Avoids subjectivity by algorithmic evaluation of terrain type and rock abundance
- Solves traveling salesman problem to find the minimum-time path to visit multiple ROIs (MSL had only one ROI)

Slopes (JEZ)



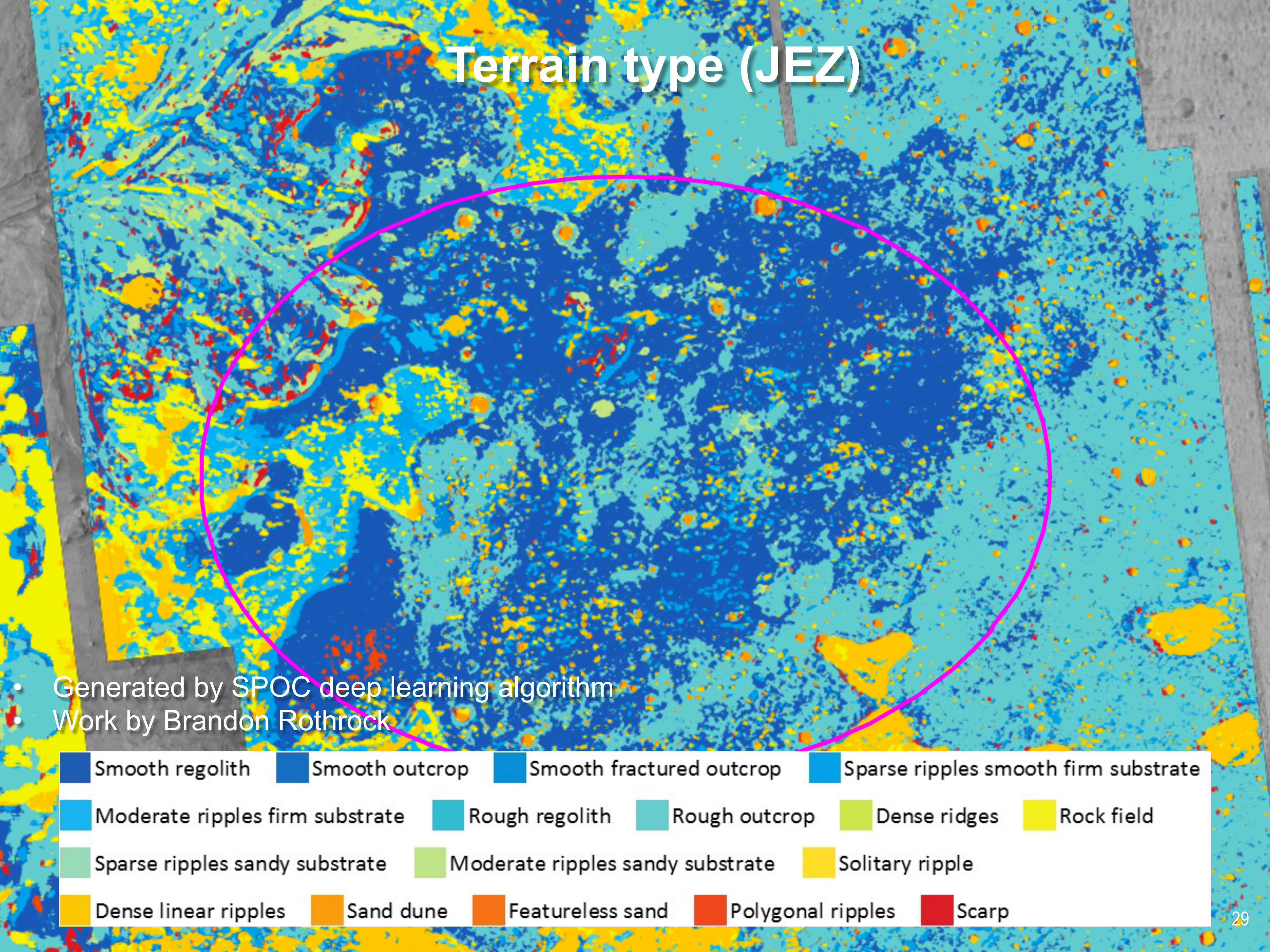
- Based on USGS DEM, used Horn method with 1m baseline
- Work by Richard Otero, Nathan Williams, Hallie Gengl

Rock CFA (Cumulative fraction of area) (JEZ)



- Generated by rock counting algorithm
- Work by Eduardo Almeida and Andres Huertas

Terrain type (JEZ)



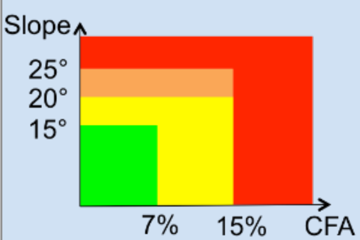
- Generated by SPOC deep learning algorithm
- Work by Brandon Rothrock

Drive Rate Estimates (Effective rate)

- 17 terrain types are categorized into 5 classes
- Optimistic and conservative estimates are assigned based on slope, CFA for each class
- Drive rates are “taxed” by path inefficiency and slip
- Assumed 2.5 hr/sol drive (Blind drive speed averaged over 2.5 hr)

Class 1
Benign Terrains

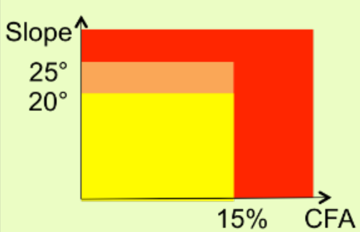
Smooth regolith
Smooth outcrop
Fractured outcrop



64.8 m/hr
52.5 m/hr
10.9 m/hr
Avoid

Class 2
Rough terrains

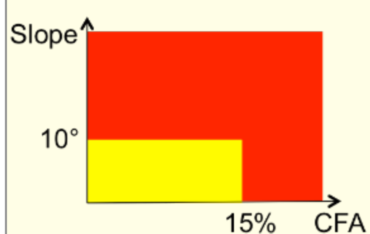
Rough regolith
Routh outcrop



24.2 – 48.5 m/hr
10.9 m/hr
Avoid

Class 3
Sandy terrains

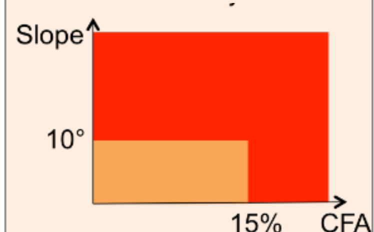
Sparse ripples firm/ sandy substrate
Moderate ripples firm/sandy substrate



10.9 – 40.8 m/hr
Avoid

Class 4
No-autonav terrains

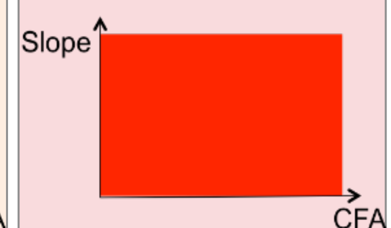
Dense ridges
Rock field
Featureless sand



10.9 m/hr
Avoid

Class 5
Untraversable

Solitary ripple
Dense linear ripples
Sand dune
Polygonal ripples
Scarp



Avoid

Traversability Maps

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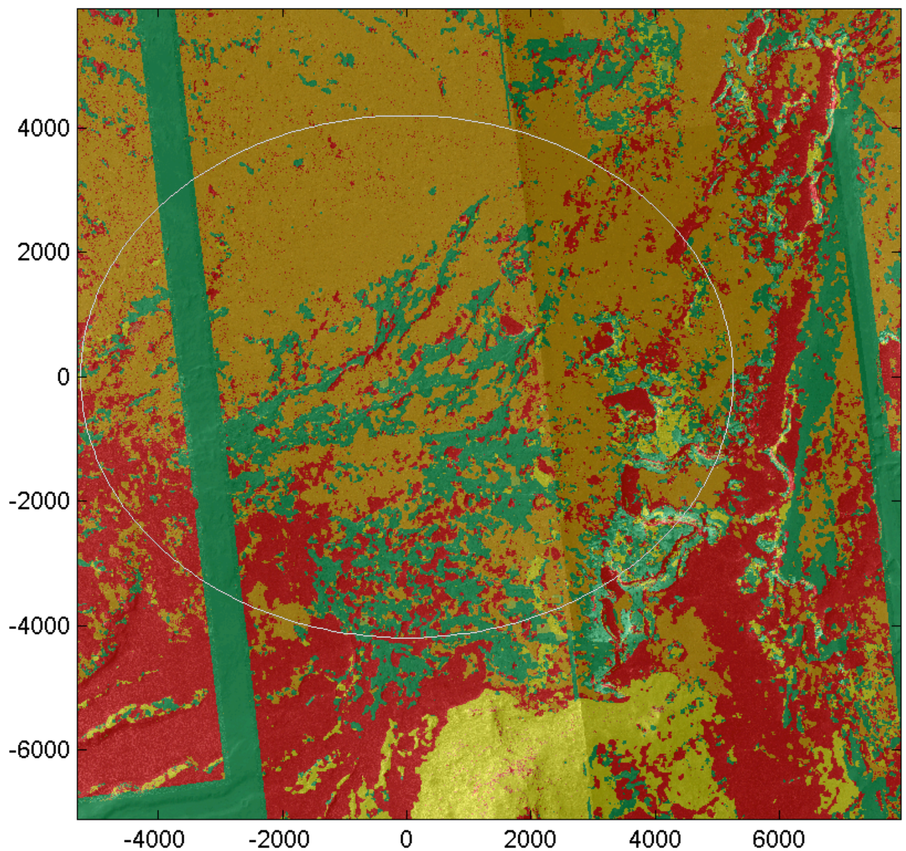
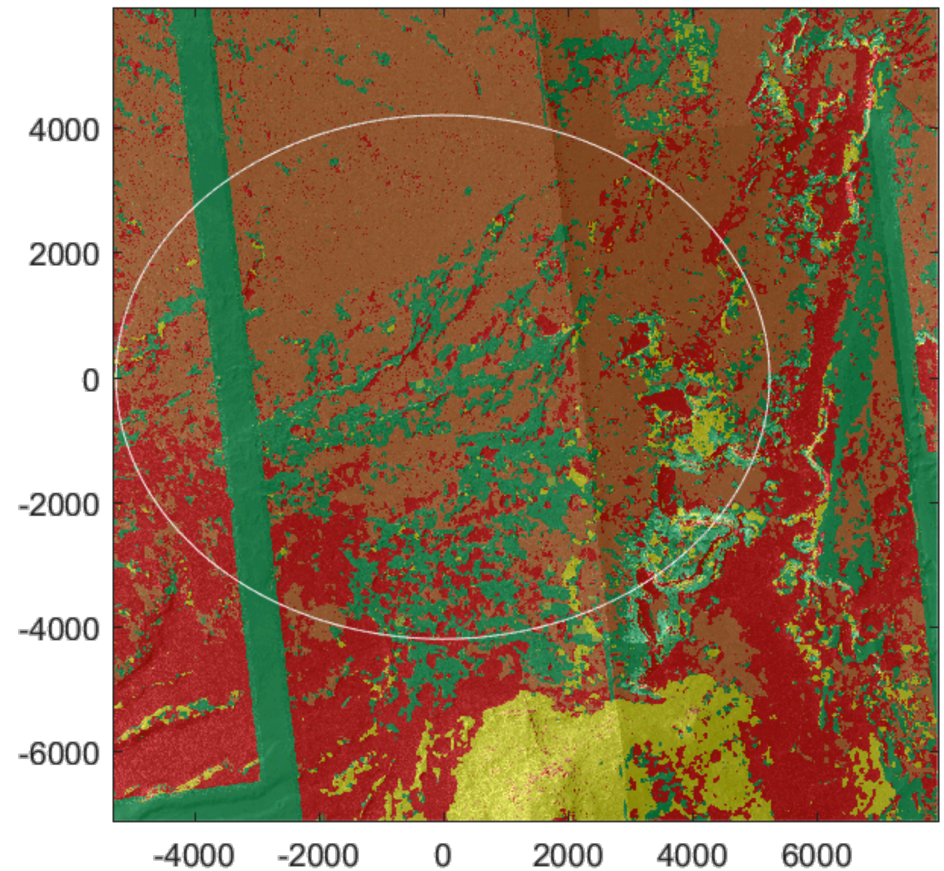
- Map terrain class/slope/CFA to driving speed at 5 m resolution
- No-data grids are treated optimistically

Optimistic



65 m/hr | 53 m/hr | 48 m/hr | 41 m/hr | 11 m/hr | Avoid

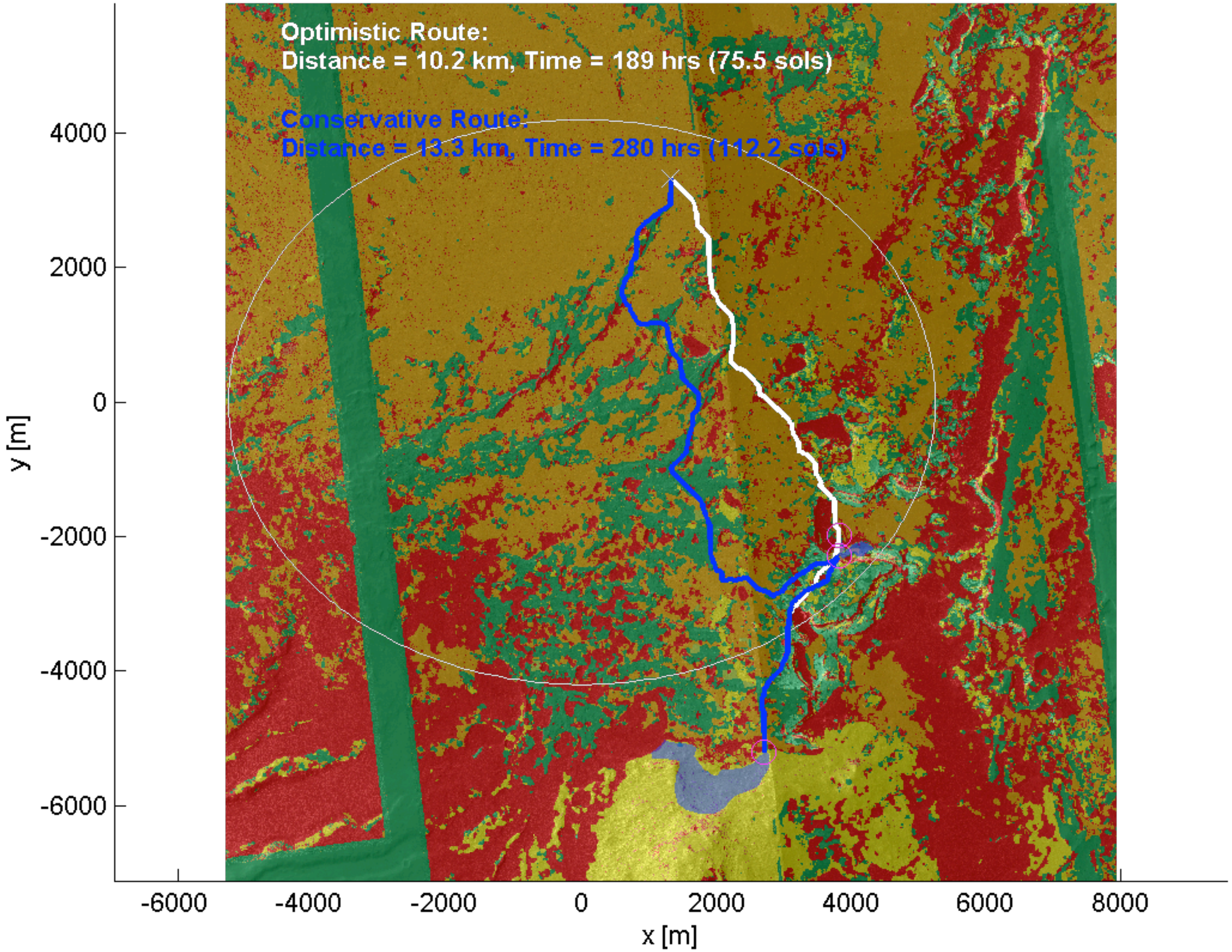
Conservative



65 m/hr | 53 m/hr | 24 m/hr | 11 m/hr | Avoid

Time-Optimal Route Planning

- Plan fastest route from a landing point to two ROIs



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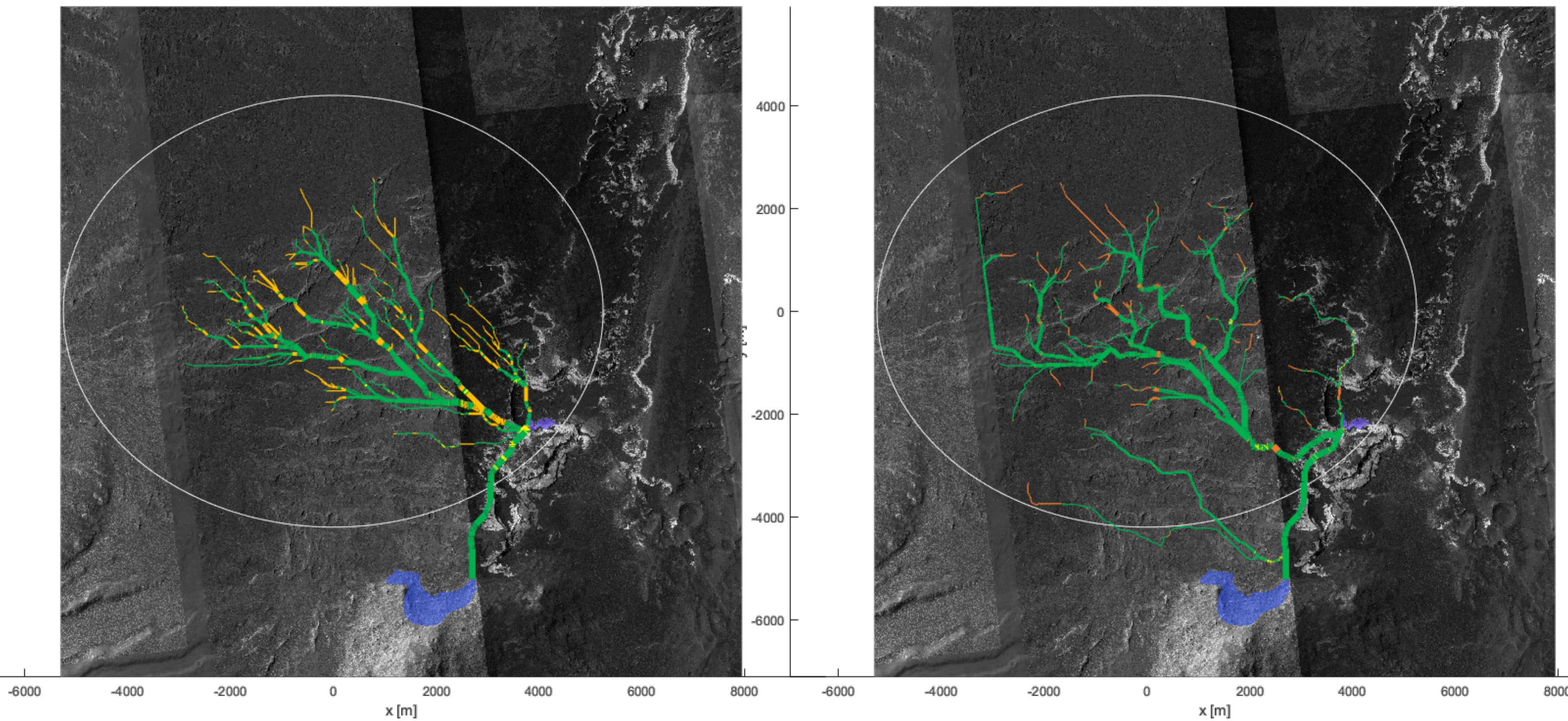
Monte-Carlo Simulation

- Monte-Carlo simulation with 8,000 landing points sampled from landing probability distribution
- Many routes converge to the most traversable terrains, forming natural “highways”

Optimistic | **Conservative**

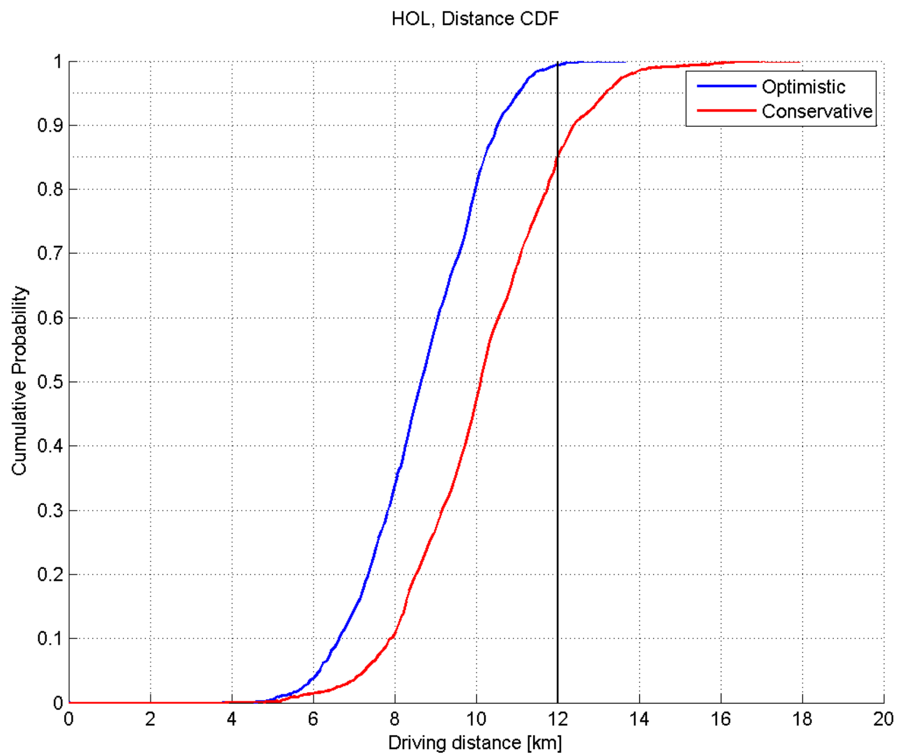


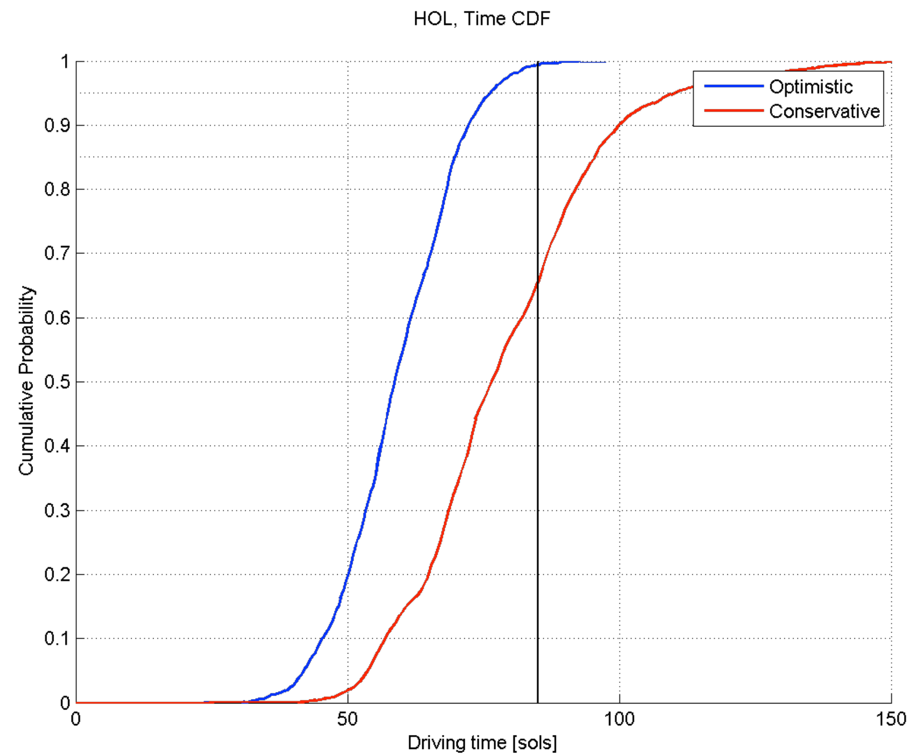
Optimistic: 65 m/hr, 53 m/hr, 48 m/hr, 41 m/hr, 11 m/hr

Conservative: 65 m/hr, 53 m/hr, 24 m/hr, 11 m/hr

Cumulative Distribution Functions

HOL (high uncertainty)

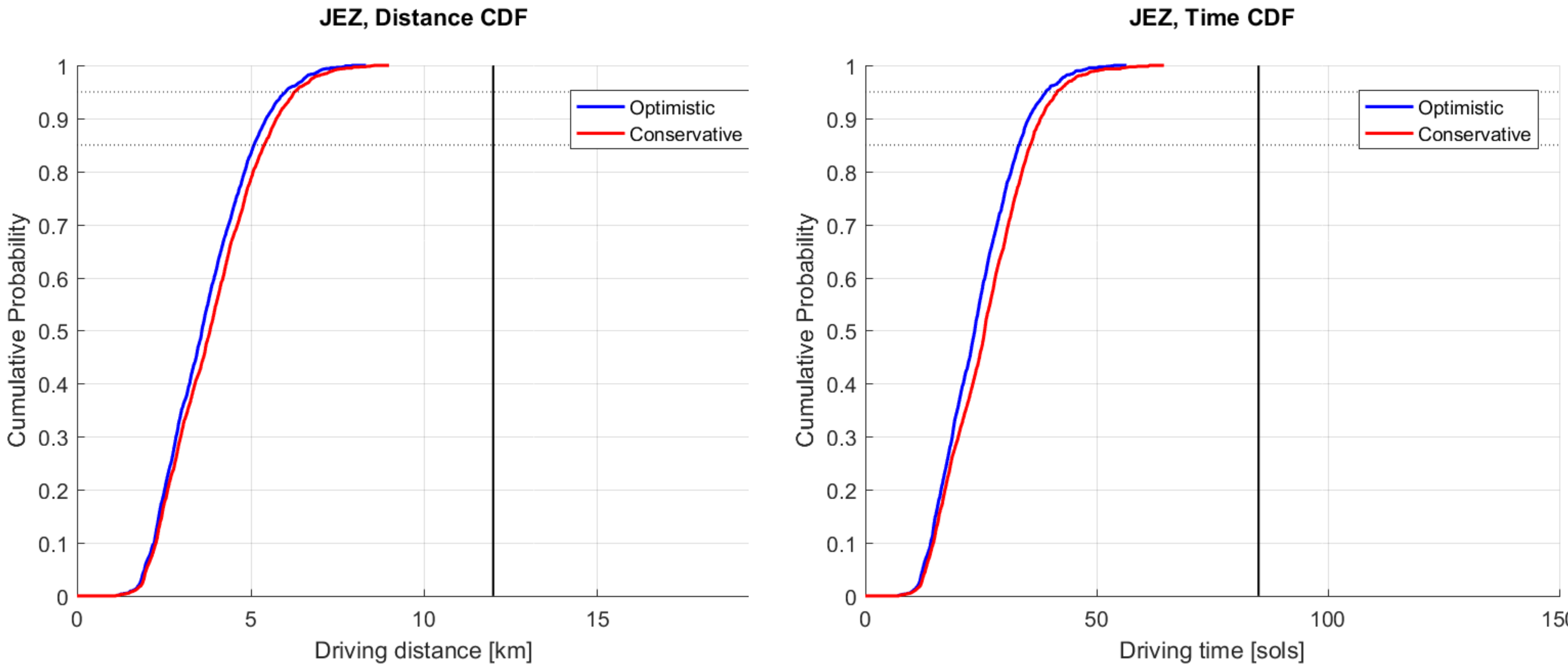




- Distance is a map distance with no added distance for slip or path inefficacy
- Slip/path inefficiency added to time

Cumulative Distribution Functions

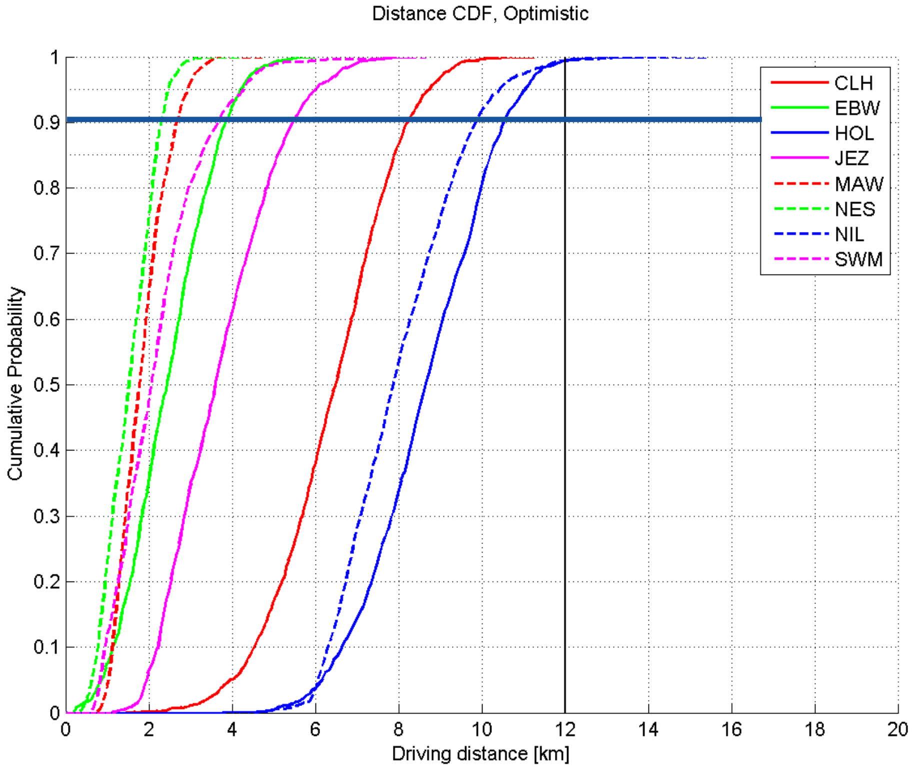
JEZ (low uncertainty)



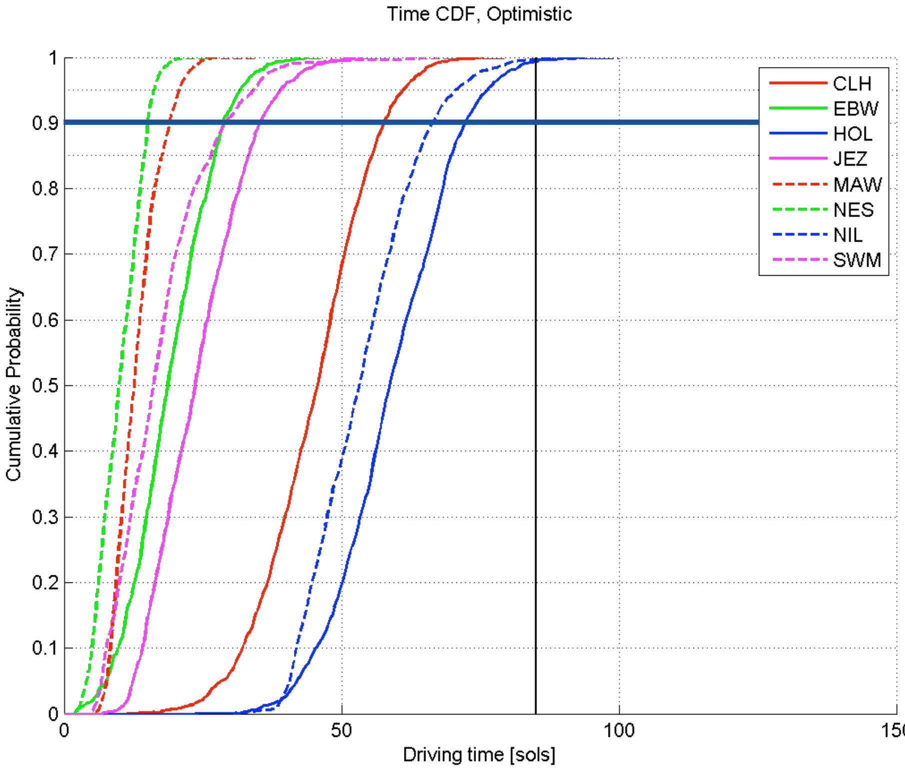
- Distance is a map distance with no added distance for slip or path inefficacy
- Slip/path inefficiency added to time

CDF for All Sites (*Optimistic*)

Distance



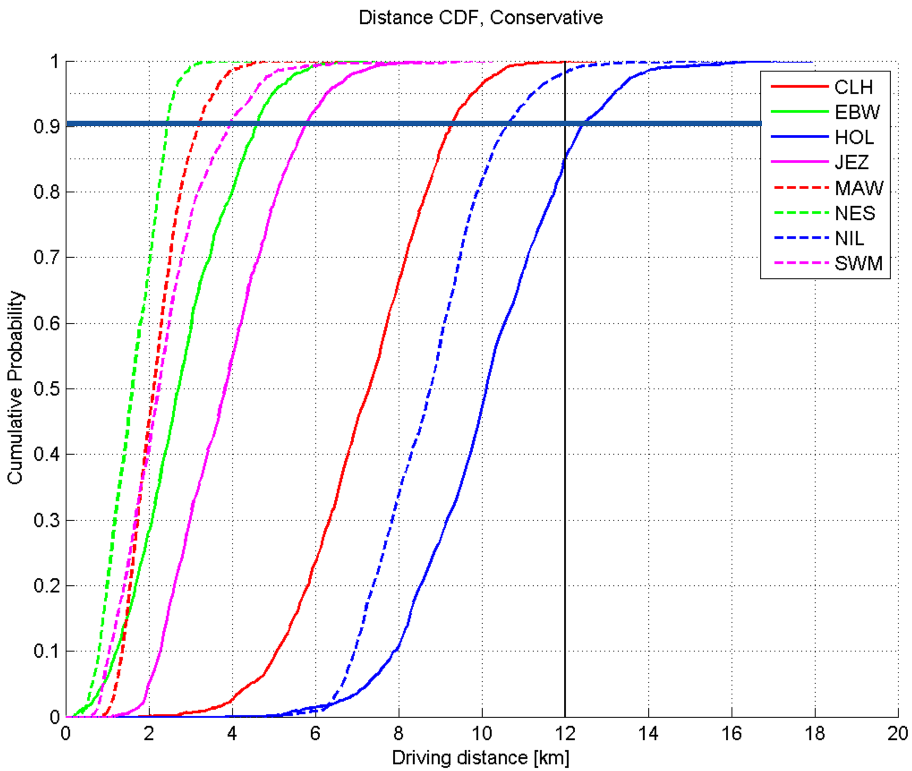
Time



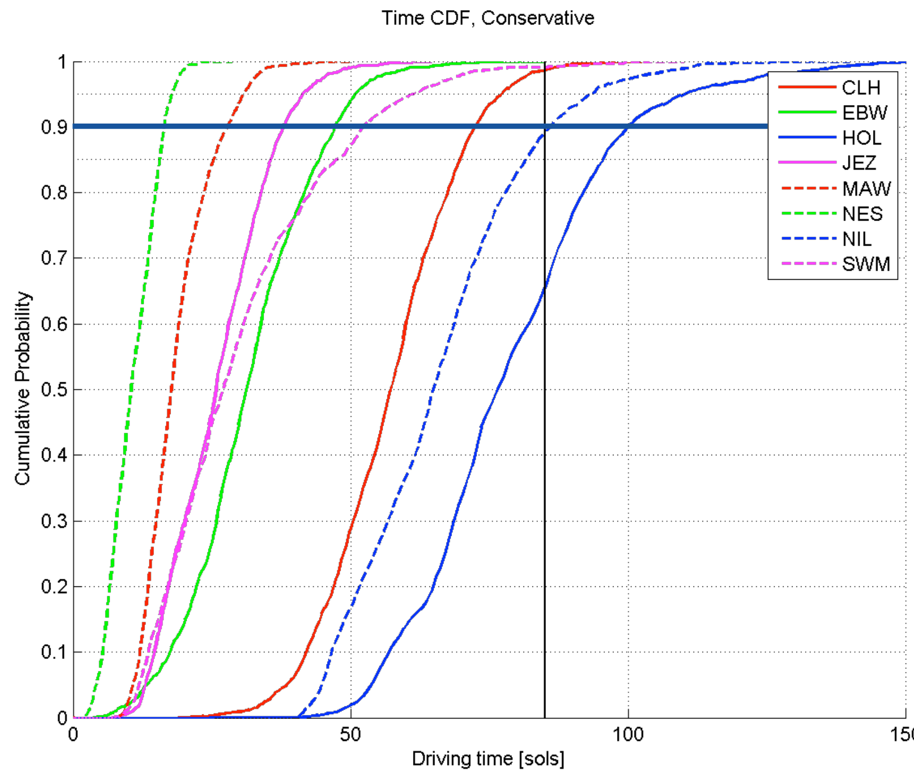
BRS requirements satisfied with >95% probability for all sites

CDF for All Sites (Conservative)

Distance



Time



- HOL satisfies BRS distance requirement with ~85% probability
- HOL satisfies BRS time requirement with ~65% probability
- NIL satisfies BRS distance requirement with ~89% probability

HOL Key Challenges

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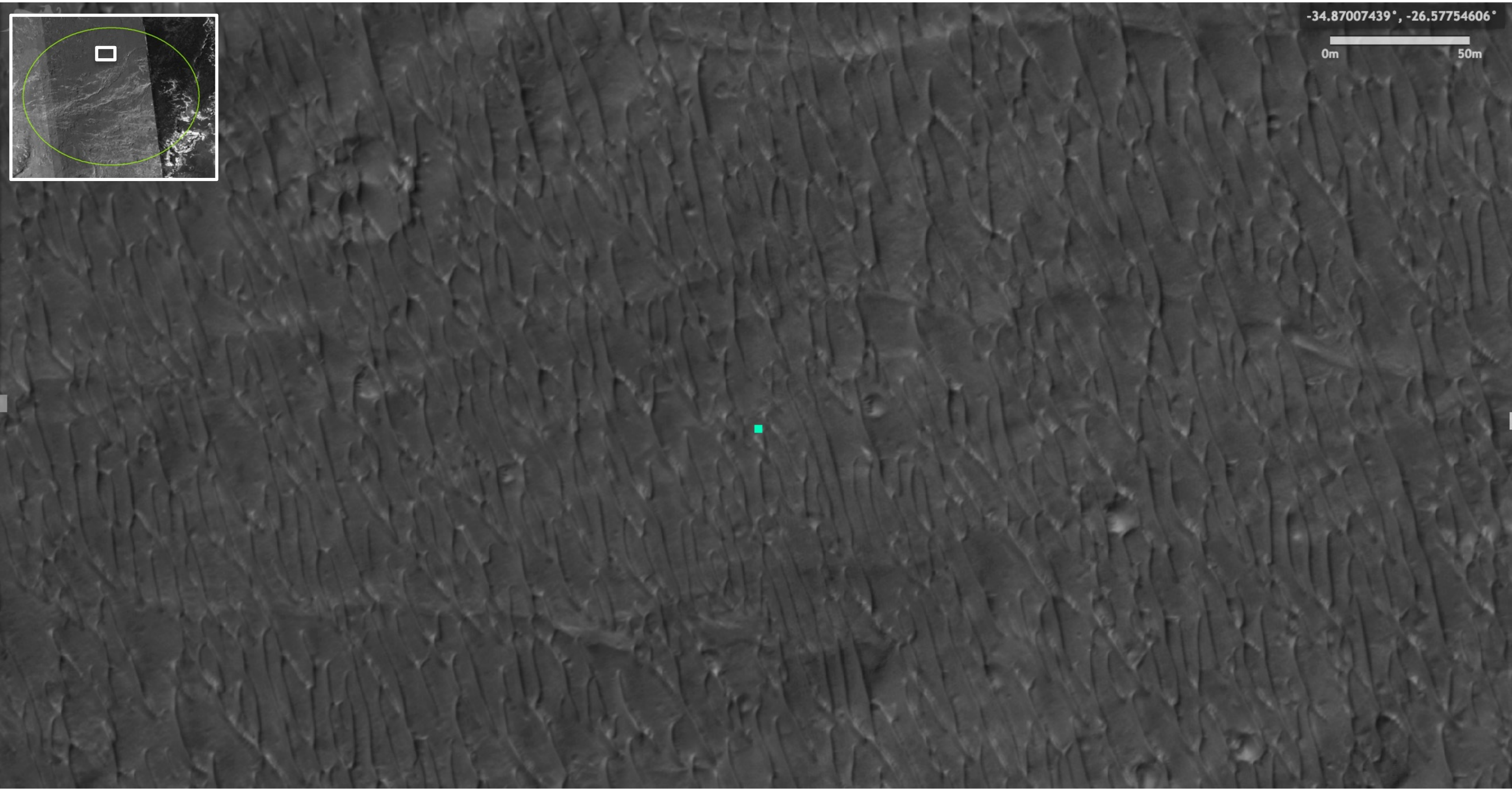
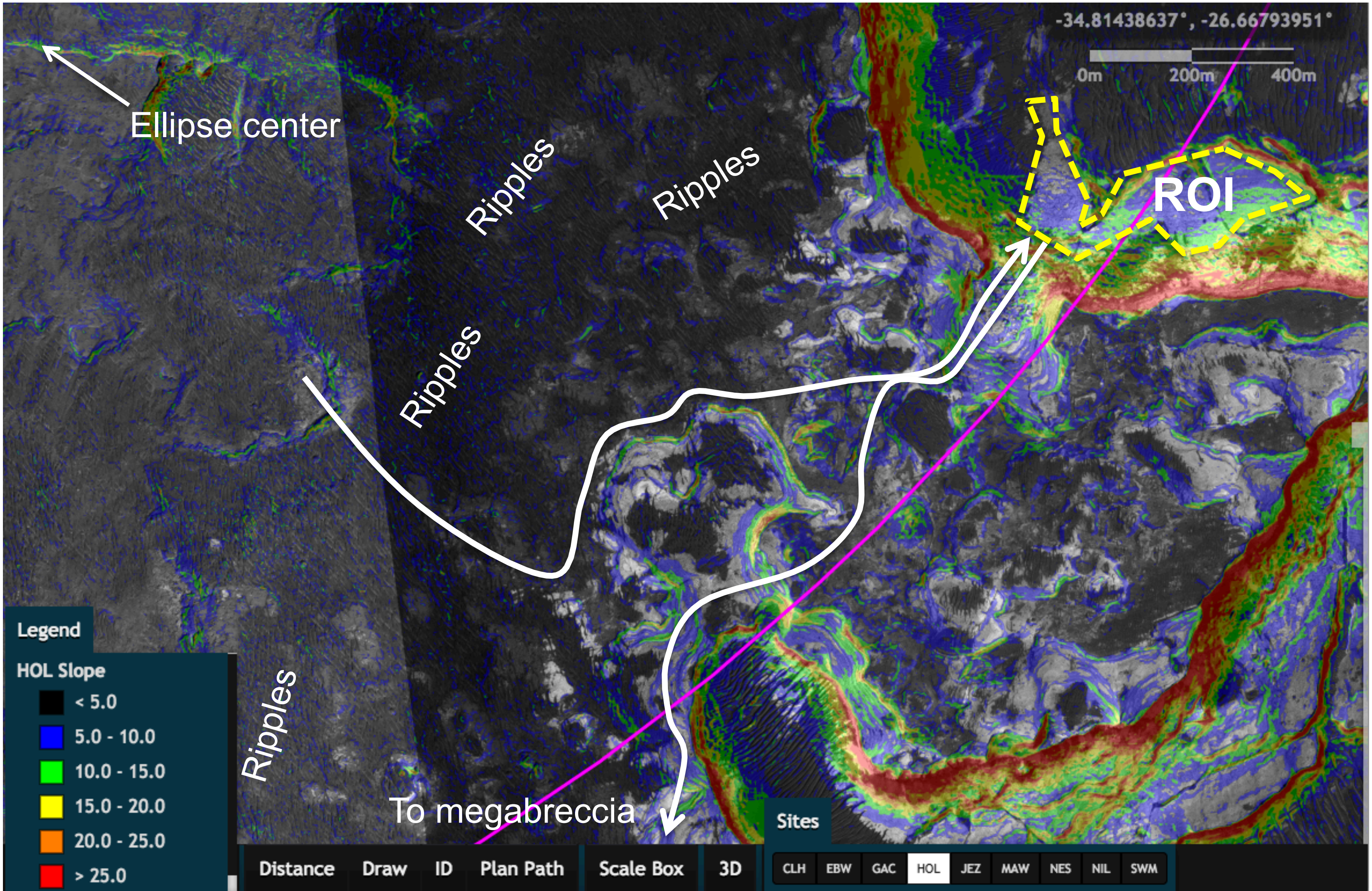
Much of the northern portion of the ellipse appears to be bedrock covered with sand ripples. Traversable due to wide troughs between ripple crests. Slow driving due to frequent terrain occlusions from ripples and lack of texture for stereo. Larger and more challenging ripples than Eberswalde.

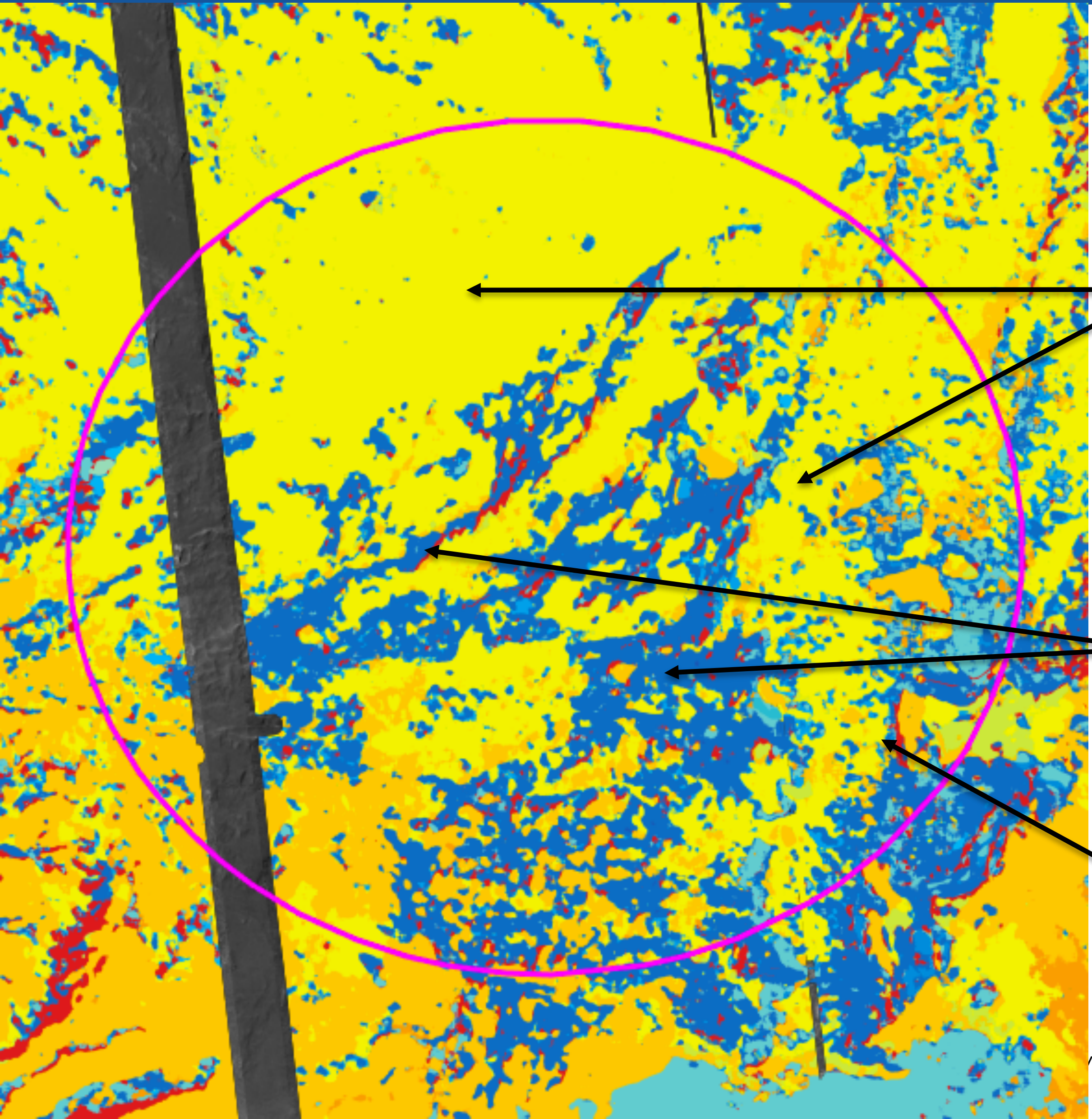
Map link



Access to Light-toned Layered Deposit ROI



HOL Traversability



Ripples [11–41 m/hr]

Smooth outcrop highways [65 m/hr]

Untraversable ripples and scarps in front of ROI

Summary of Status & Results

	90% Time [Sol]	90% Distance [km]	Traversability challenges
BRS	85	12	(Baseline reference scenario)
CLH	57.7 – 72.7	8.3 – 9.3	Go-to site
EBW	28.9 – 47.6	3.8 – 4.6	Mantling unit with ripples Scarps on delta
HOL	72.4 - 100.6	10.6 – 12.5	Go-to site; >60% covered by potentially no-Autonav ripples; highways exist but in unfavorable directions Access to ROI (layered deposit) challenging due to high slope/sand
JEZ	35.5 – 38.1	5.5 – 5.8	High CFA on SE of ellipse but ROIs are on NW
MAW	19.1 – 28.0	2.7 – 3.2	Surface roughness could limit the speed of Autonav, but can achieve mission with conservative estimate
NES	15.1 – 16.5	2.3 – 2.4	Buttes and sand deposits, but localized and easy to go around
NIL	66.7 – 86.7	9.9 – 10.6	Go-to site Ripples but mitigated by highway in the favorable direction
SWM	29.6 – 52.5	3.7 - 4.0	Scarps, but traversable routes seem to exist across

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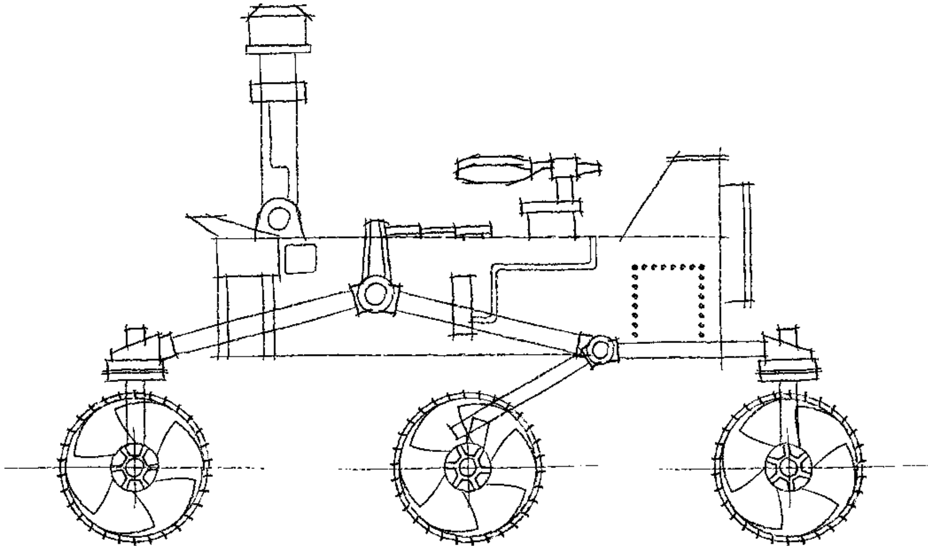
Mars 2020 Mission Planning

Site-Specific Surface Mission Performance Modeling



Rob Lange
Sarah Milkovich
Jennifer Trosper
Travis Wagner

31 January 2017

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How do we model the surface mission?

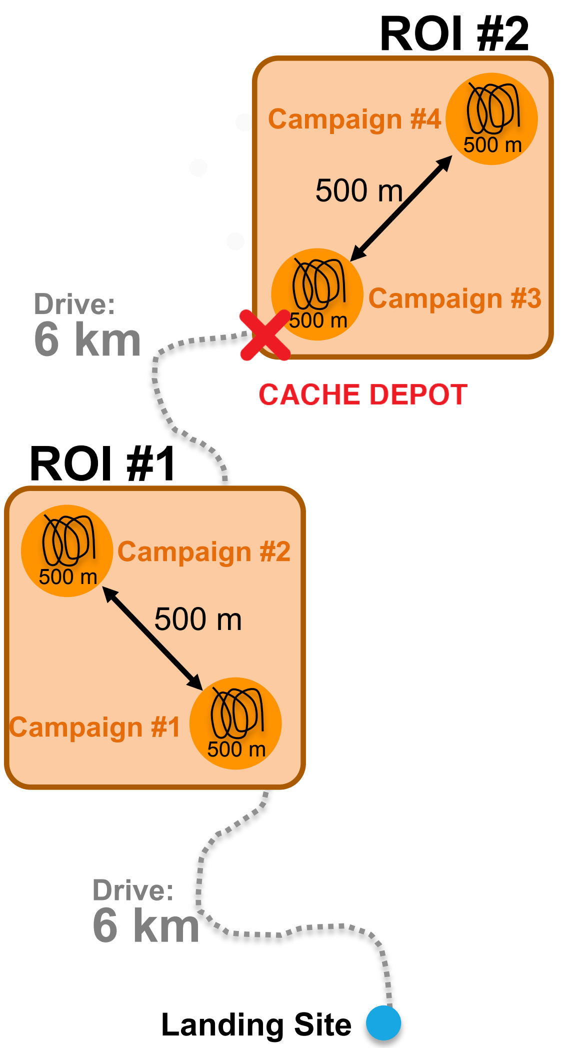
- We have developed a suite of tools/models that, when used in combination, can help us to **evaluate key mission performance metrics** such as:
  - Mission duration to accomplish surface mission objectives
  - Ops Efficiency needed to accomplish mission objectives
  - Mission data volume
  - Rover traverse distances and speed
  - Amount of science investigation conducted
    - number of sols, number of observation types, number of locales investigated, number of samples collected, data volume generated, …

- Some of the tools/models implemented:
  - MTTT (Mars Twenty-Twenty Traversability) *new for M2020*
    - Drive route planning and terrain classification
  - MSLICE for Mars 2020 *modified from MSL*
    - Planning tool used for building high-fidelity sol scenarios
  - Operations Efficiency Analysis *new for M2020*
    - Developed by Mars Exploration Program office to evaluate Mars orbiter relay characteristics w.r.t. ground staffing profile
  - TOAST orbiter relay simulation
  - Surface Mission Performance Model *new for M2020*

Baseline Reference Scenario (BRS)

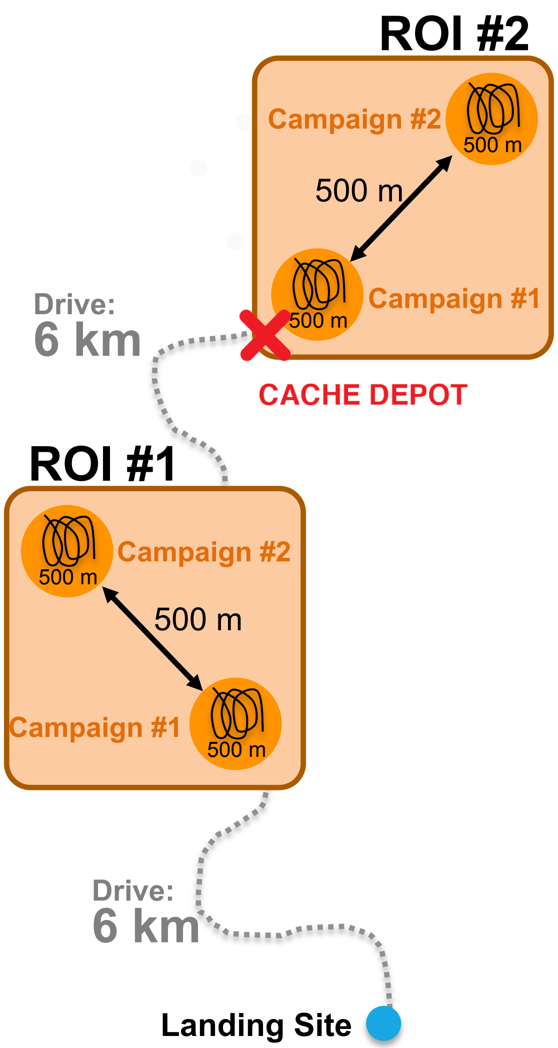
The project system shall have the **capability to perform the following Baseline Reference Scenario** (BRS) surface mission within **1.25 Mars years (836 sols)**, which includes the following:

- Conduct the investigations required to meet science objectives A and B and meet technology objective D
- Explore 2 distinct **Regions Of Interest** (ROI) of approximately **1 km x 1 km** area.
- For each ROI:
  - **6 km of long traverse** to reach
  - Conduct **2 science Campaigns** per ROI
  - Investigate **5 stratigraphic Units** per ROI
  - **1.5 km of local traverse** to explore, consisting of:
    - **500 m "walkabout" driving per Campaign**
    - **500 m driving between Campaigns**
  - Acquire **9 cached samples** per ROI, consisting of
    - 7 Rock and/or Regolith samples
    - 2 Witness Blanks
- Acquire **2 rock and/or regolith "waypoint" samples** at any point during the mission
- A single **Cache Depot** at a location near ROI #2



Baseline Reference Scenario description

- The BRS is a representation of a **generic** M2020 surface mission.
- The BRS mission is intended to be **stressing** in its definition, but not bounding.
- The BRS is not real but is informed by expected surface mission characteristics. Similarly, actual landing sites have unique operational characteristics.
- The BRS is used to drive key L3 & L4 capability requirements necessary to accomplish mission objectives.



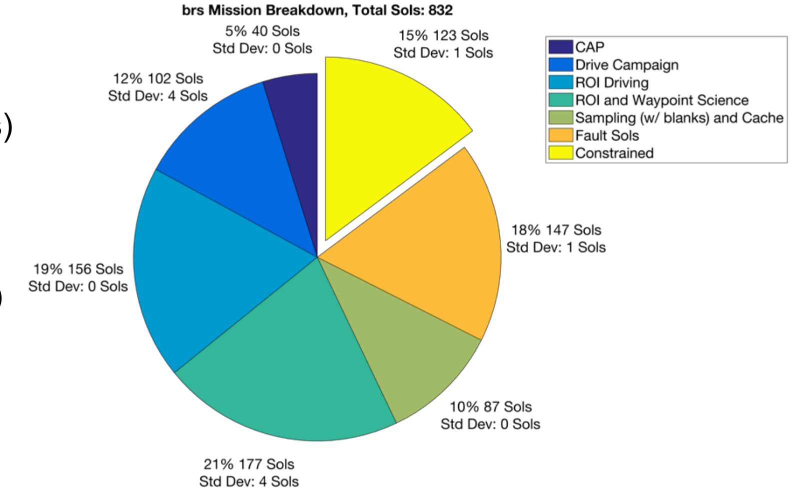
BRS Mission Performance

Jet Propulsion Laboratory
California Institute of Technology

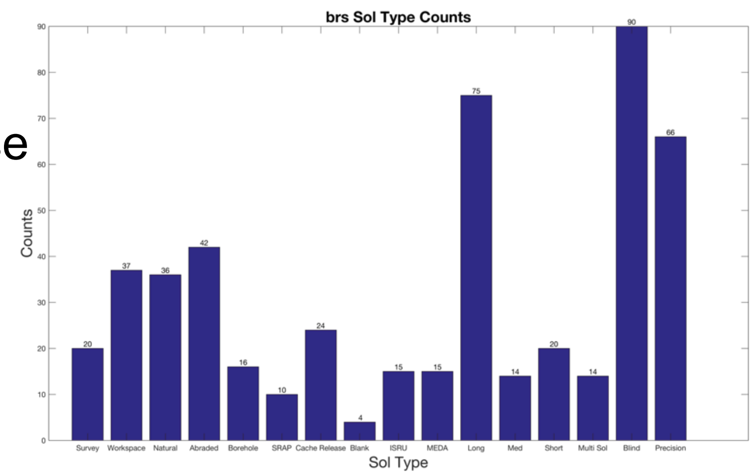
Mars 2020 Project

Results of Surface Mission Performance analysis for Surface Phase **CDR** (Feb-2017) for the **Baseline Reference Scenario**

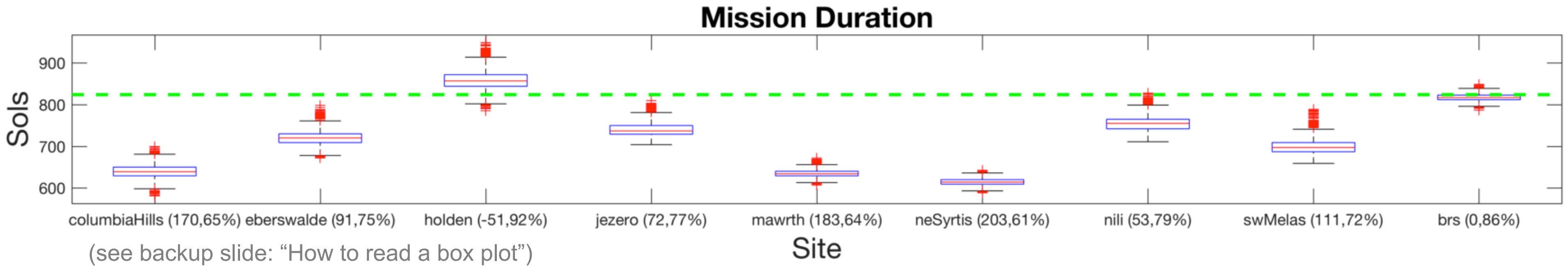
1.25 Mars Year prime mission duration (836 sols)
(includes 0.25 MY Mission System margin)
\+ 0.25 MY "unencumbered" Project margin
= 1.5 Mars Year total mission duration (1004 sols)



- ✓ BRS Mission completed
- ✓ 20 samples collected
- ✓ 19 km driven
- ✓ 40 unconstrained sols for commissioning phase
- ✓ Holidays & Solar Conjunction included
- ✓ Assumes "Bin 3" landing site environment
- ✓ 84% Ops Efficiency over 1.25 MY mission



Site-Specific Mission Performance Results



(see backup slide: "How to read a box plot")

- Results of Mission Performance monte-carlo modeling shown above.
  - Comparing landing site performance to Baseline Reference Scenario 80th-percentile mission duration (green-dashed line).

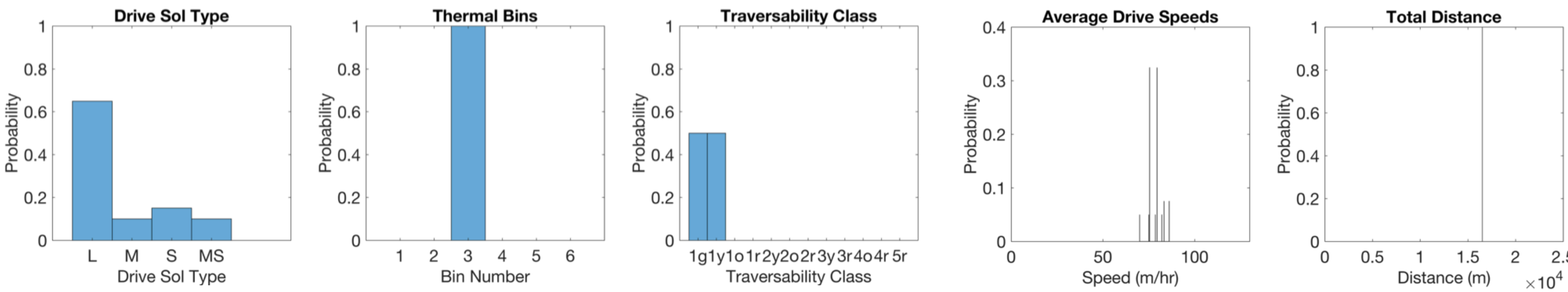
- Site-specific mission performance analysis includes 4 dominant sources of variability:
  1. Mobility characteristics (MTTT)
     - Terrain characteristics for driving (slope, rock abundance, terrain classification)
     - Drive route planning to science campaign locations
  2. Science campaign definitions from site proposers
  3. Seasonal environmental effect on operations
  4. Sol Type scenario models (subject to seasonal constraints)

(1) Site-Specific Mobility Characteristics

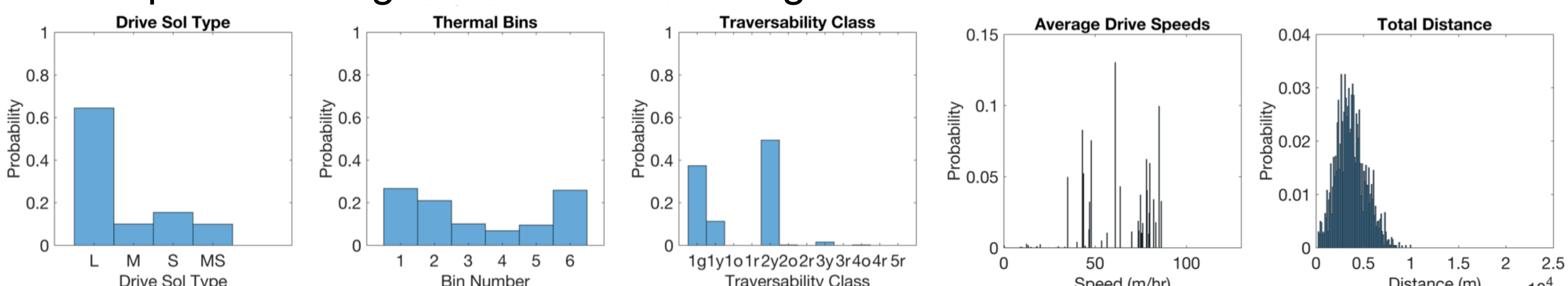
MTTT

Mission Performance Model
- Drive Sol Types
- Thermal Environments
- Drive Times
- Drive Path Distance
- Traversability Classifications
- Drive Modes & Rates

BRS Drive Modeling:



Example <Landing Site> Drive Modeling:



(2) Site-Specific Science Exploration

- Science exploration objectives and approach can vary from site-to-site.
- The Project has collaborated with site proposers to define and prioritize potential **Regions-of-Interest** (ROI) for detailed science exploration within each landing site.
- ROI locations also provide mobility path planning destinations, which gives overall traverse distance characteristics for each site

(2) Site-Specific ROI Summary

ROI #2

	Campaigns	Units	Samples	ROI Drive Distance	Walkabout Drive Dist.
Eberswalde	3	3	7	200	500
Columbia Hills	1	2	5	100	500
Holden	2	4	6	1000	500
Jezero	2	2	3	200	500
Mawrth	1	2	4	500	500
NE Syrtis	2	4	6	200	500
Nili	2	6	6	500	500
SW Melas	2	4	6	100	500
BRS	2	5	7	500	500

ROI #1

	Campaigns	Units	Samples	ROI Drive Distance	Walkabout Drive Dist.
Eberswalde	3	3	7	200	500
Columbia Hills	2	6	8	100	500
Holden	2	6	8	100	500
Jezero	2	10	10	500	500
Mawrth	3	6	9	300	500
NE Syrtis	2	4	6	200	500
Nili	2	4	6	500	500
SW Melas	2	6	8	500	500
BRS	2	5	7	500	500

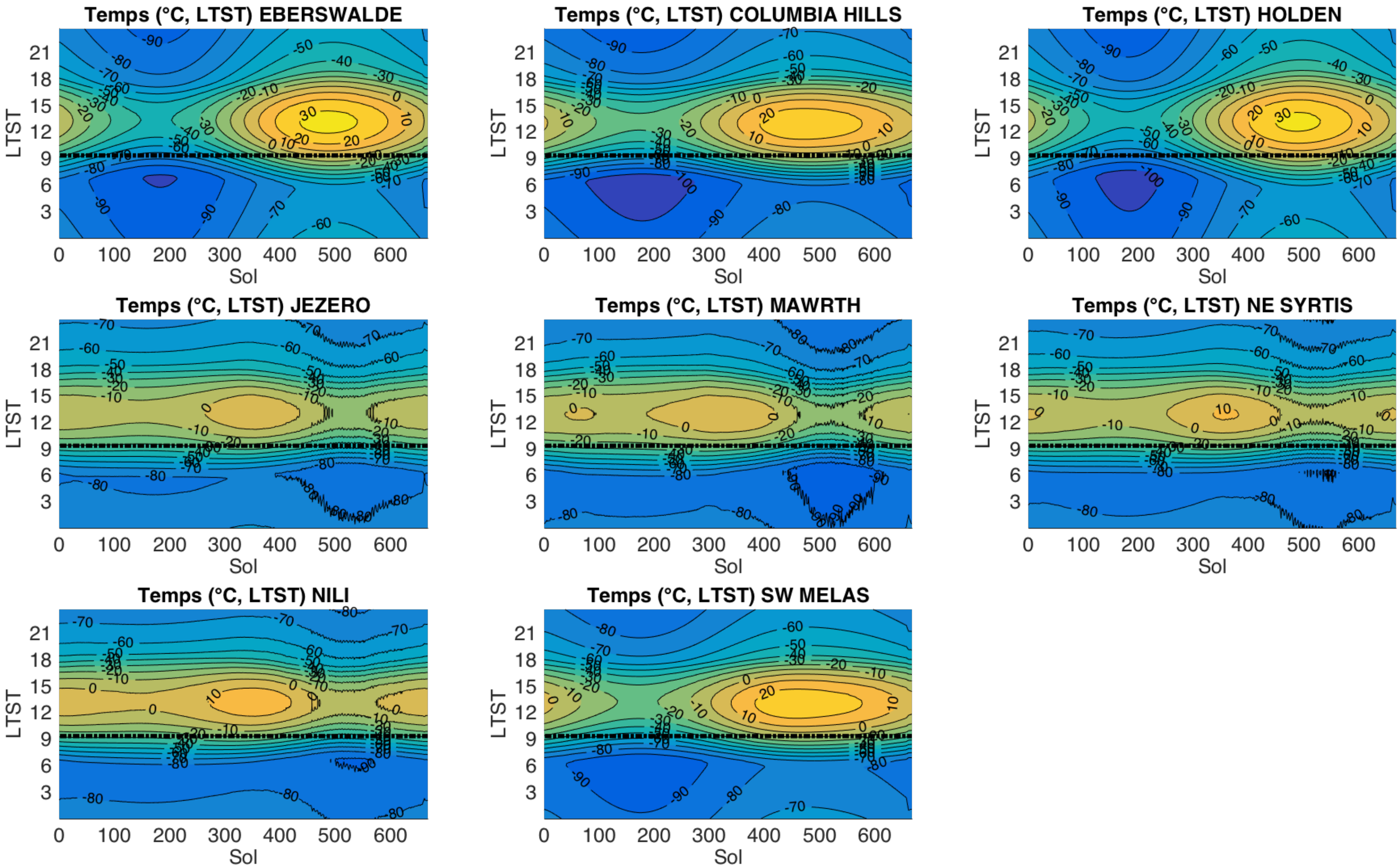
Waypoint(s)

Rock Sample	Regolith Sample
1	1
2	1
2	0
2	1
2	1
3	1
3	1
2	0
1	1

Site-Specific ROI & Waypoint Scenario Totals

Total Campaigns	Total Units	ROI Samples	Waypoint Samples	Witness Sample	Total Samples	Total Distance	
6	6	14	2	4	20	3800	Eberswalde
3	8	13	3	4	20	1600	Columbia Hills
4	10	14	2	4	20	3100	Holden
4	12	13	3	4	20	2700	Jezero
4	8	13	3	4	20	2600	Mawrth
4	8	12	4	4	20	2400	NE Syrtis
4	10	12	4	4	20	3000	Nili
4	10	14	2	4	20	2600	SW Melas
4	10	14	2	4	20	3000	BRS

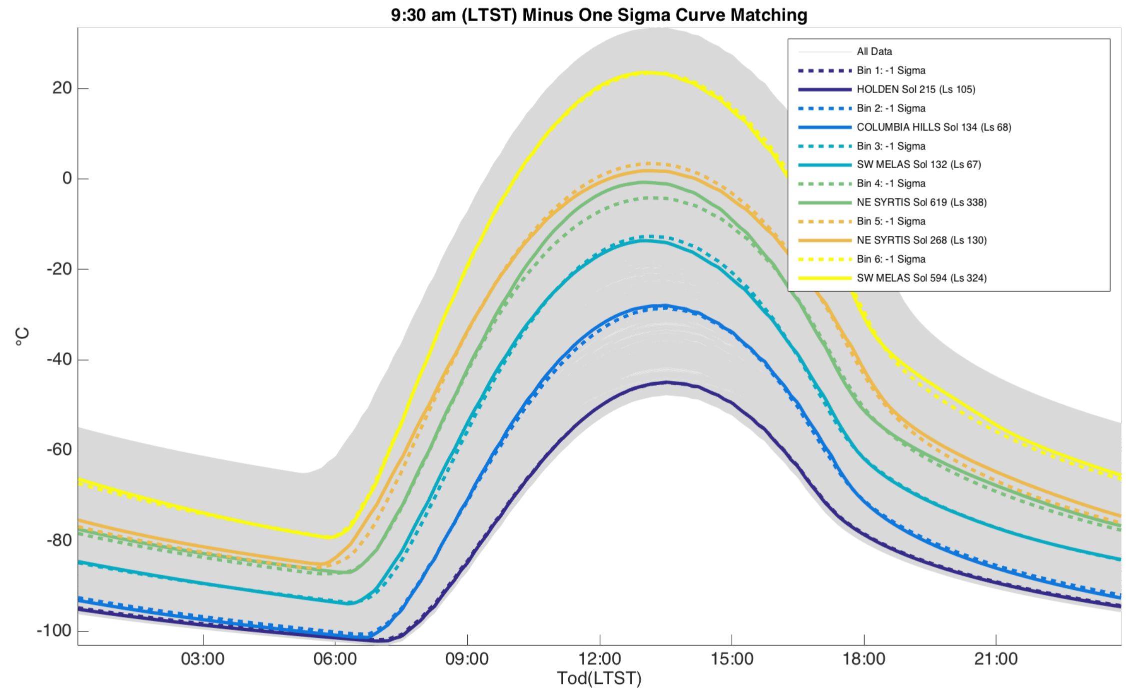
(3) Site-Specific Seasonal Environments



(3) Seasonal Environments – “6 Bins”

[top-right] 6 diurnal environments (aka ”Bins”) derived from, and optimal to, all landing site annual environmental variability.

[bottom-right] Percentage of environment bin usage over 1 MY for each landing site, based on Sol ranges defined by curve-fit optimization to 9:30 LTST ground temperature .

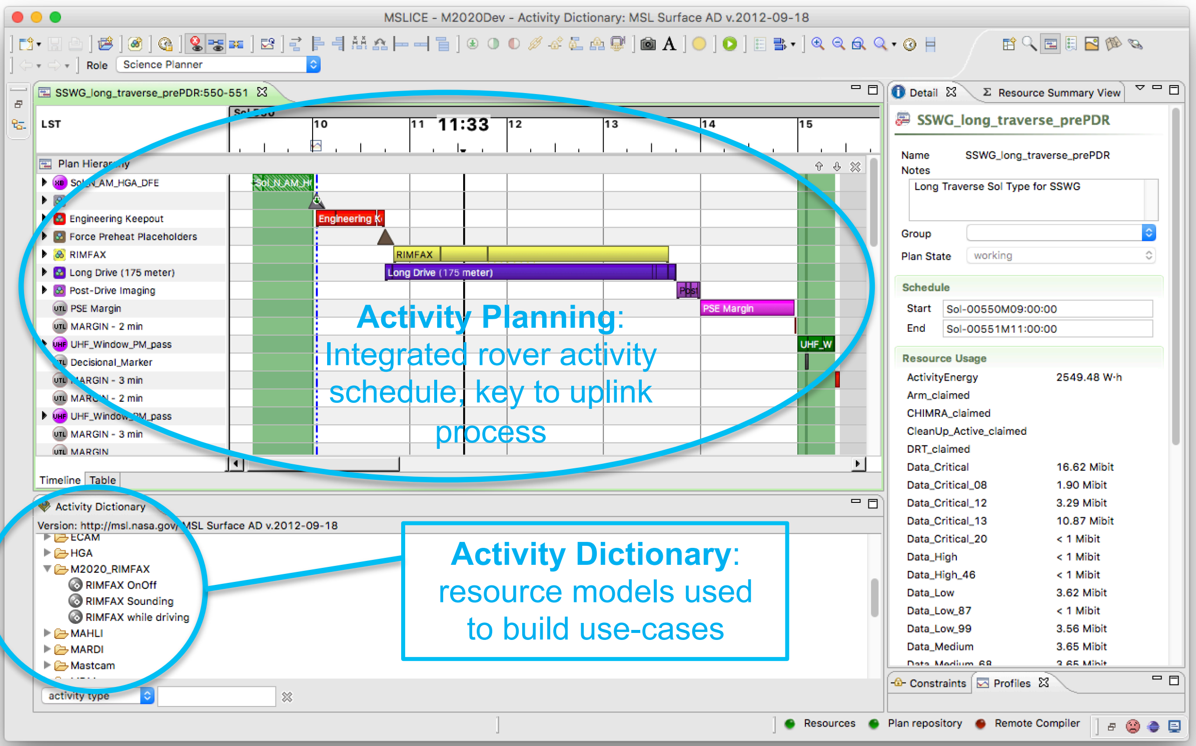


6 environments were provided to Payload and FS thermal teams for analysis on survival heating, mechanism heat-to-use, instrument warm-up and ops time-of-day constraints.

	Bin:	1	2	3	4	5	6
1	Eberswalde	24%	16%	13%	8%	12%	28%
2	Columbia Hills	0%	33%	16%	11%	18%	21%
3	Holden	29%	14%	11%	8%	11%	27%
4	Jezero	0%	0%	29%	64%	8%	0%
5	Mawrth	0%	11%	19%	42%	27%	0%
6	NE Syrtis	0%	0%	21%	62%	16%	0%
7	Nili	0%	0%	24%	52%	24%	0%
8	SW Melas	0%	0%	32%	14%	17%	36%

(4) Sol Type Scenario Designs

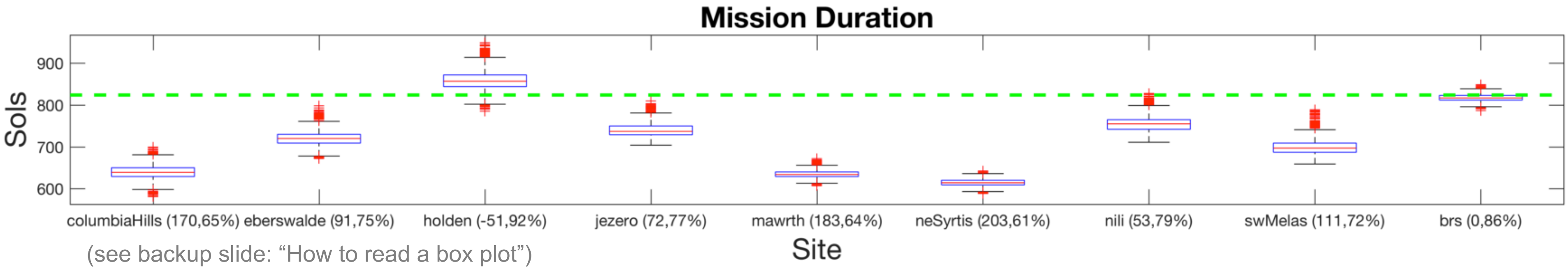
- Mission scenario modeling employs MSLICE planning tool
  - (Inherited from MSL operations. Adapted for M2020 Mission Planning.)
  - Provides ops-like sol scenario planning and resource/constraint management
  - High-fidelity resource modeling (time/duration, power/energy, data volume)



Sol Type Scenario Resource Usage Summary

Sol Type	Description	Sol Type Duration (# sols) Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6
Survey Remote Sensing	Detailed remote sensing of new location, used to inform sol path planning	1	1	1	1	1	1
Workspace Remote Sensing	Detailed remote sensing of Robotic Arm workspace	1	1	1	1	1	1
Natural Proximity Science	Investigate 2 surface targets	2	1	1	1	1	1
Abraded Proximity Science	Abrade surface target and perform detailed investigation	3	2	2	2	2	2
Sample Coring & Borehole Science	Acquire rock/regolith sample and investigate borehole	4	4	3	3	3	3
ISRU	MOXIE full O2 production cycle	1	1	1	1	1	1
MEDA-dedicated	MEDA intensitve observation mode. Can be scheduled on a Constrained Sol	1	1	1	1	1	1
		Drive time available (hours)					
Long Drive	Blind+Autonav drive modes. Optimized for longest possible drive	1	2	2.2	3	3	3.25
Medium Drive	Blind+Autonav drive modes with ~1 hour limited remote sensing	1	1.2	1.4	2	2	2.5
Short Drive	Blind-only drive mode, limited to ~30 meters. Remaining resources for remote sensing	0.9	0.9	0.9	1	1	1
Precision Approach	10-meter approach to proximity science "Parking Spot". RSM workspace imaging only.	1	1	1	1	1	1
Precision Approach with Go & Hover	10-meter approach to proximity science "Parking Spot" AND deploy arm for WATSON imaging of workspace, plus RSM workspace imaging.	n/a	n/a	1	1	1	1
Multi-sol Drive	Autonav drive mode without ground-in-the-loop. Scheduled on Constrained sol only.	1	2	2.2	3	3	3.25

Site-Specific Mission Performance Results



(see backup slide: “How to read a box plot”)

- Results of Mission Performance monte-carlo modeling shown above.

- Conclusions
  - Project level requirements and design support the BRS mission
  - All site-specific analyses except for Holden are within the BRS mission capability
    - Combination of Holden environment and go-to ROI locations cause it to exceed BRS mission for the 80th percentile mission duration.

Engineering Summary

Engineering Summary

Site	EDL	Surface	Comments
Columbia Hills			
Eberswalde			
Holden			Likely to exceed the prime mission duration to accomplish science objectives
Jezero			
Mawrth			
NE Syrtis			
Nili Fossae			
SW Melas			Lack of confidence in atmosphere modeling results coupled with significant terrain hazards bordering the landing ellipse raise concerns

All candidate landing sites are viable; however, have some engineering concerns with Holden and SW Melas

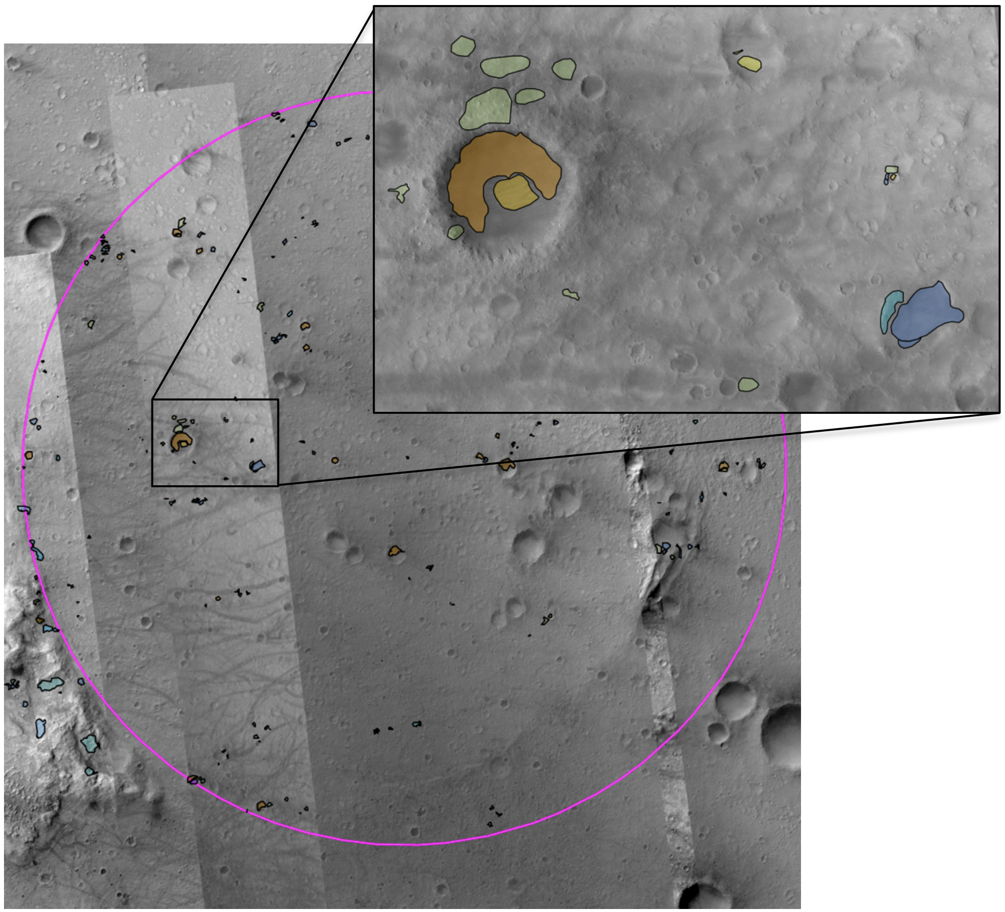
Backups

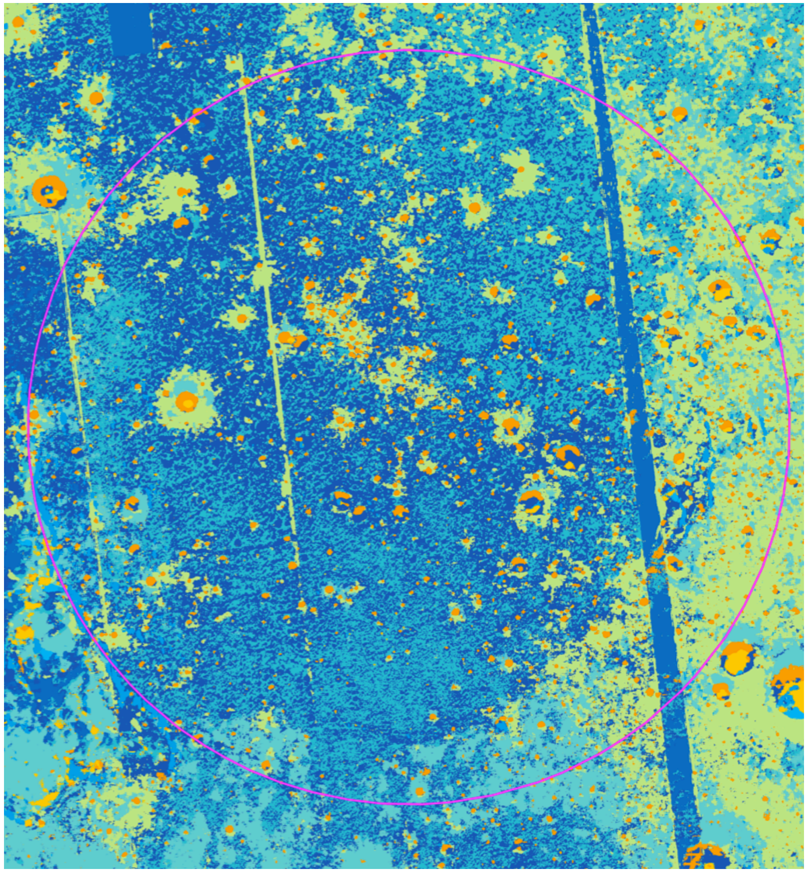
Abbreviations

	On Mars	On Earth
CLH	Columbia Hills	Coolah Airport (Australia)
EBW	Eberswalde	Ebolowa Airport (Cameroon)
HOL	Holden Crater	Holikachu Airport (AK, USA)
JEZ	Jezero Crater	N/A
MAW	Mawrth	Malden Airport (MO, USA)
NES	Northeast Syrtis Major	East 34th Street Heliport (NY, USA)
NIL	Nili Fossae Trough	N/A
SWM	Southwest Melas Basin	Suia-Missu Airport (Brazil)

Terrain Classification

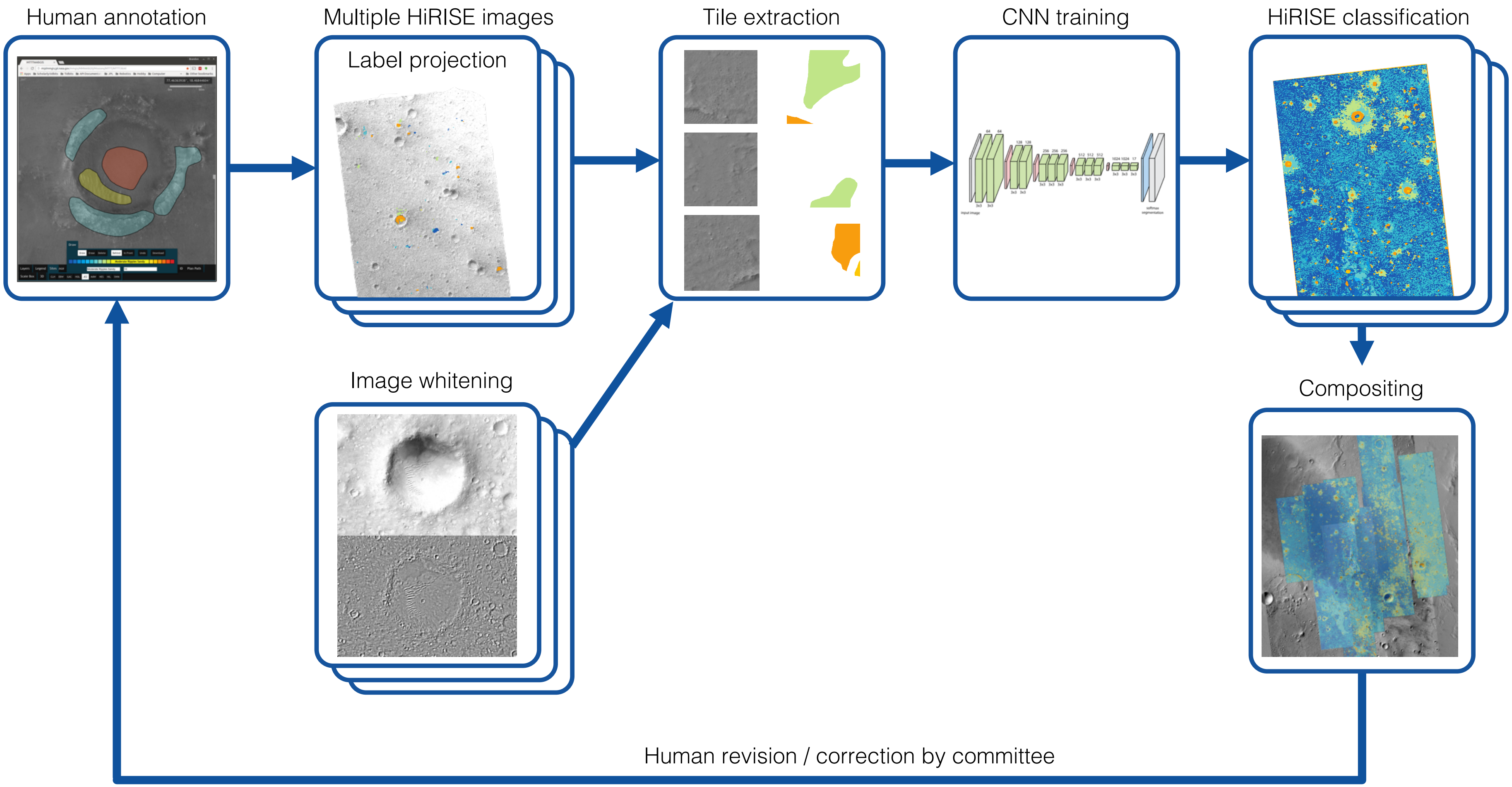
- Machine learning algorithm (deep neural network) takes a small sample of terrain classification training data and apply it to the entire landing site





Terrain Classification Workflow

- Terrain classification is iteratively refined through corrections provided by human experts



Drive rate estimates (Base rate)

Jet Propulsion Laboratory
California Institute of Technology

- 17 terrain types are categorized into 5 classes
- Optimistic and conservative estimates are assigned based on slope, CFA for each class
- Drive rates are “taxed” by path inefficiency and slip

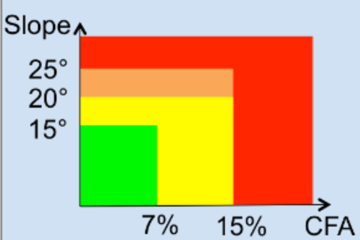
Base rate

Class 1
Benign Terrains

Smooth regolith

Smooth outcrop

Fractured outcrop

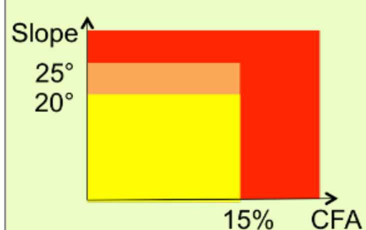


- 75 m/hr (Fast autonav)
- 70 m/hr (Slow autonav)
- 30 m/sol (Blind only)
- Avoid

Class 2
Rough terrains

Rough regolith

Routh outcrop

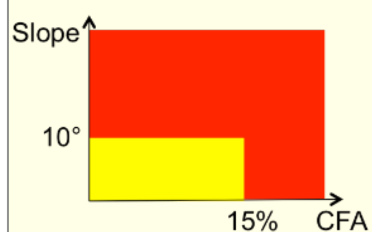


- **35 - 70 m/hr**
- 30 m/sol
- Avoid

Class 3
Sandy terrains

Sparse ripples firm/ sandy substrate

Moderate ripples firm/sandy substrate



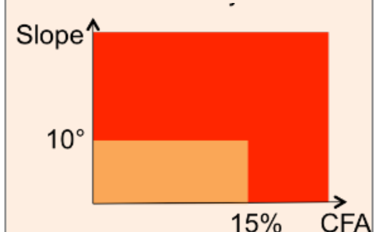
- **30 m/sol - 70 m/hr**
- Avoid

Class 4
No-autonav terrains

Dense ridges

Rock field

Featureless sand



- 30 m/sol
- Avoid

Class 5
Untraversable

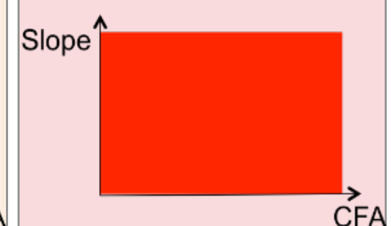
Solitary ripple

Dense linear ripples

Sand dune

Polygonal ripples

Scarp



- Avoid

Drive rate estimates (Path inefficiency / Slip)

Jet Propulsion Laboratory
California Institute of Technology

- Path inefficiency: (actual path length - strategic path length) / strategic path length
  - Accounts for inefficiency due obstacle avoidance
- Slip: (commanded path length - actual path length) / commanded path length

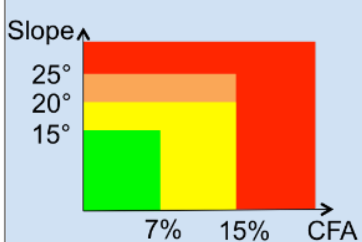
Path Inefficiency % / Slip %

Class 1
Benign Terrains

Smooth regolith

Smooth outcrop

Fractured outcrop



10% / 5%

20% / 10%

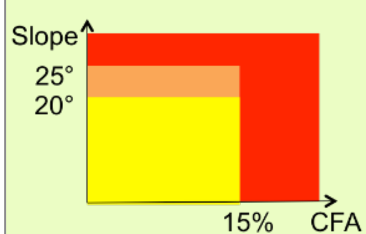
10% / 0%

Avoid

Class 2
Rough terrains

Rough regolith

Routh outcrop



30% / 10%

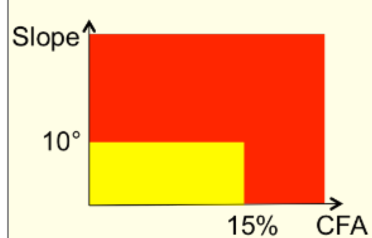
10% / 0%

Avoid

Class 3
Sandy terrains

Sparse ripples firm/ sandy substrate

Moderate ripples firm/sandy substrate



10 -20% / 0-30%

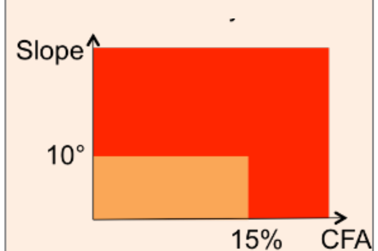
Avoid

Class 4
No-autonav terrains

Dense ridges

Rock field

Featureless sand



10% / 0%

Avoid

Class 5
Untraversable

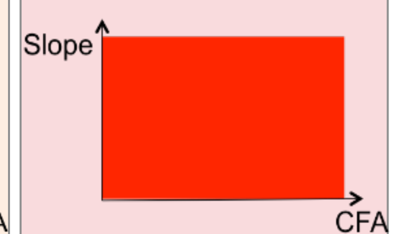
Solitary ripple

Dense linear ripples

Sand dune

Polygonal ripples

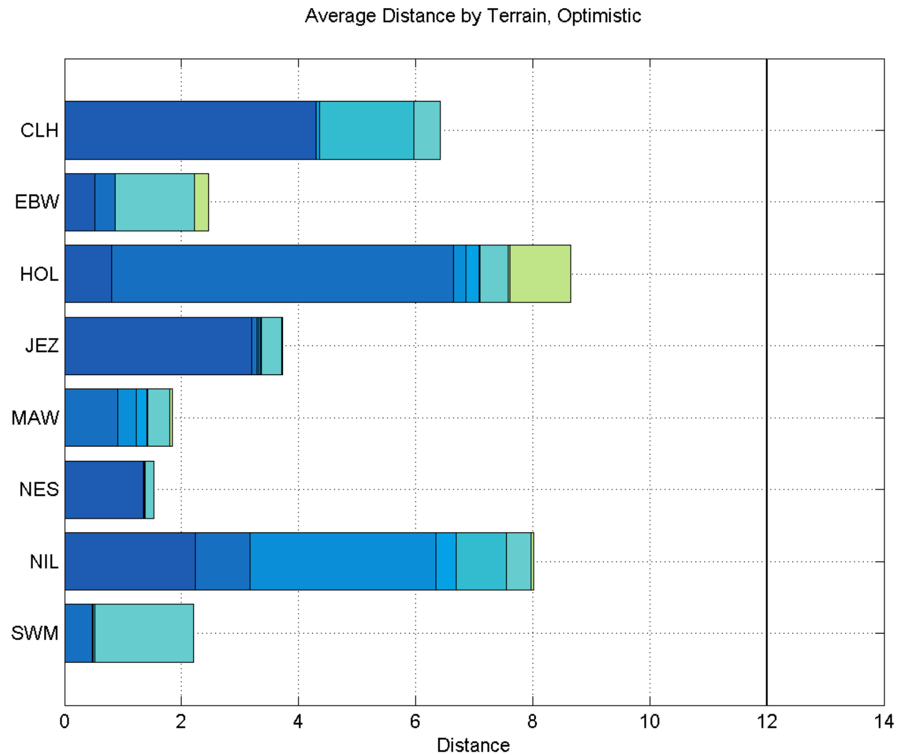
Scarp



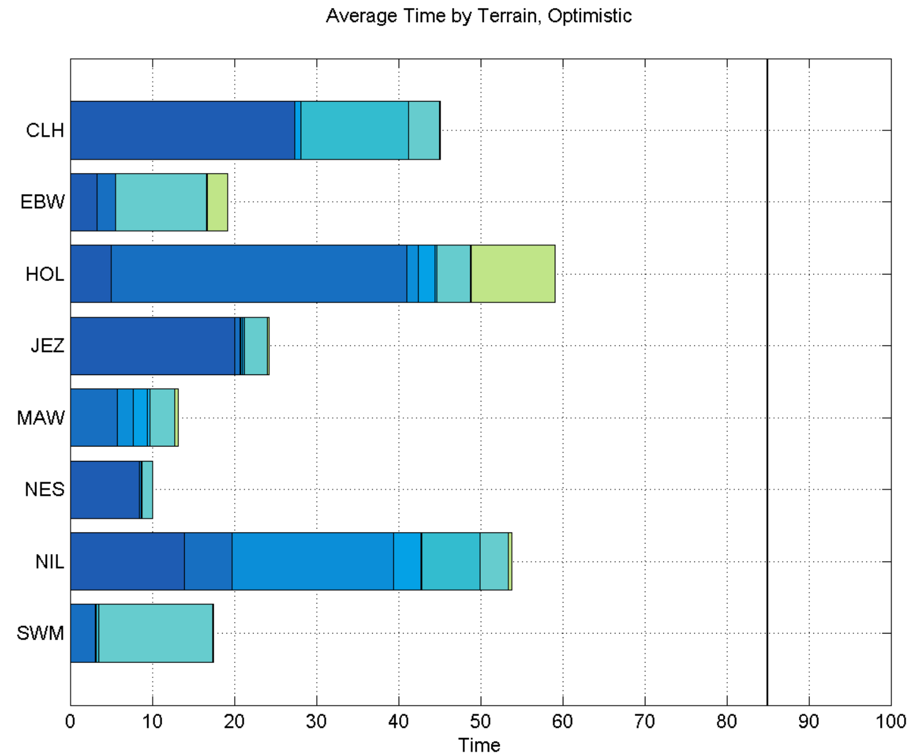
Avoid

Terrain Class Distribution (Optimistic)

Distance



Time



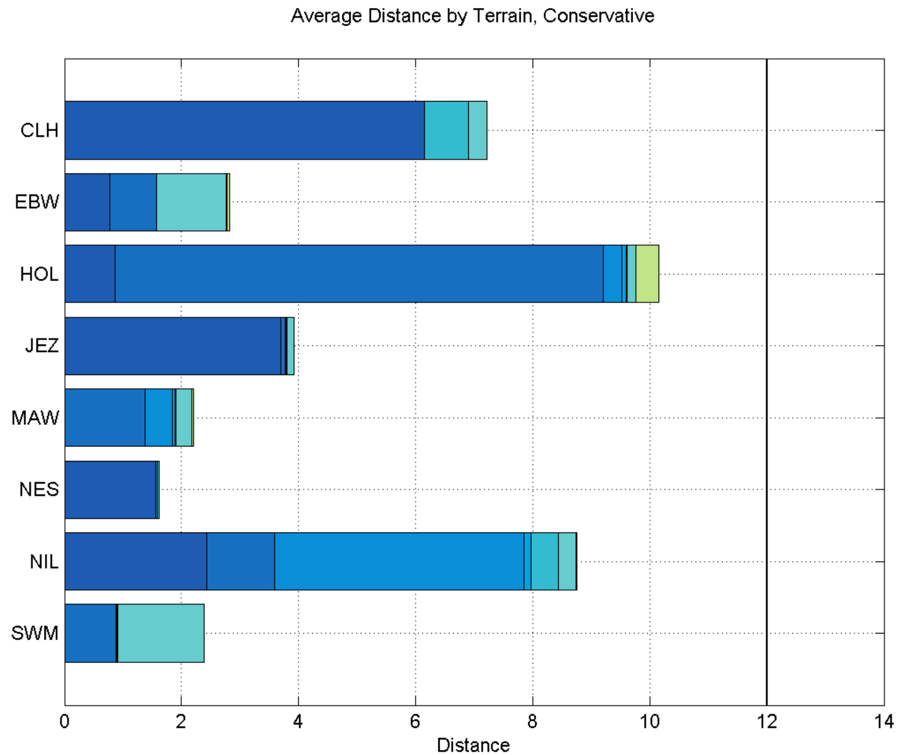
A Smooth regolith
B Smooth outcrop
C Smooth fractured outcrop
D Sparse ripples smooth firm substrate
E Moderate ripples firm substrate
F Rough regolith
G Rough outcrop
H Dense ridges
I Rock field
J Sparse ripples sandy substrate
K Moderate ripples sandy substrate
O Featureless sand

Terrain Class Distribution (Conservative)

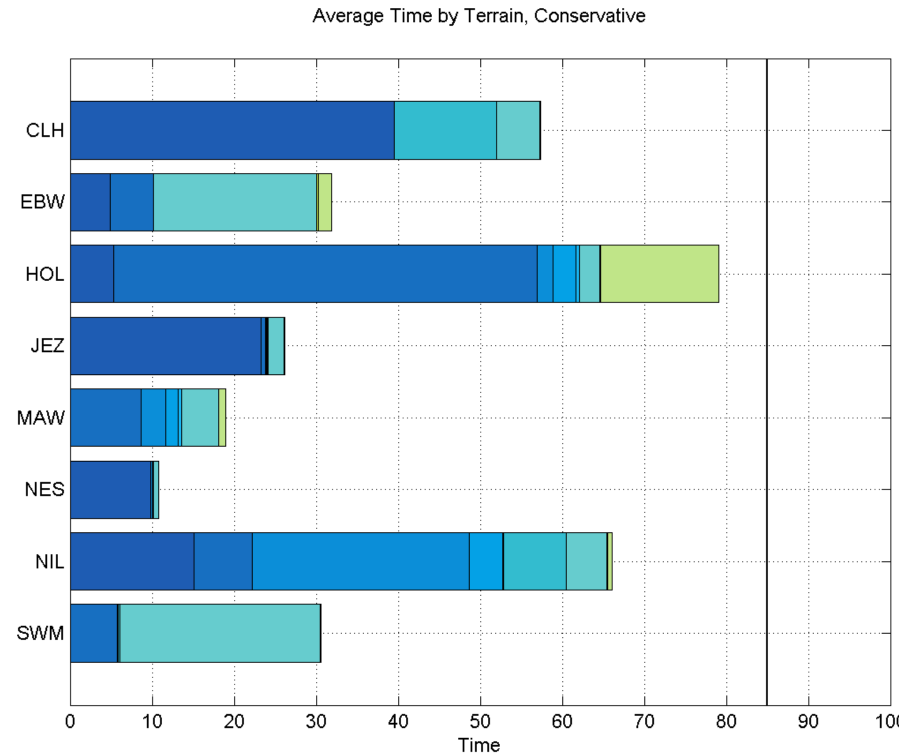
Jet Propulsion Laboratory
California Institute of Technology

Mars 2020 Project

Distance



Time



A Smooth regolith | B Smooth outcrop | C Smooth fractured outcrop | D Sparse ripples smooth firm substrate
E Moderate ripples firm substrate | F Rough regolith | G Rough outcrop | H Dense ridges | I Rock field
J Sparse ripples sandy substrate | K Moderate ripples sandy substrate | O Featureless sand

Pre-Decisional: For Planning and Discussion Purposes Only

HOL

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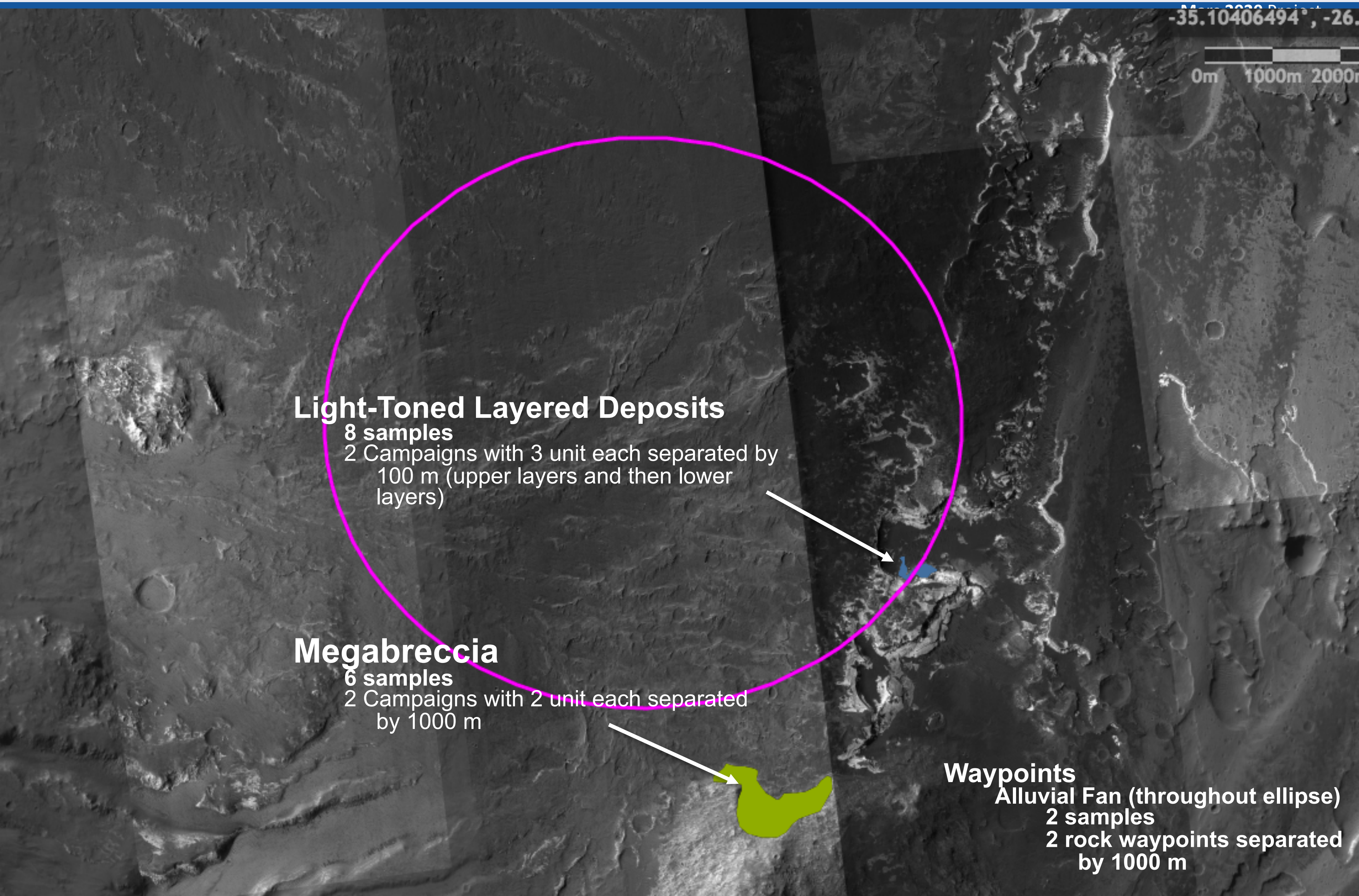
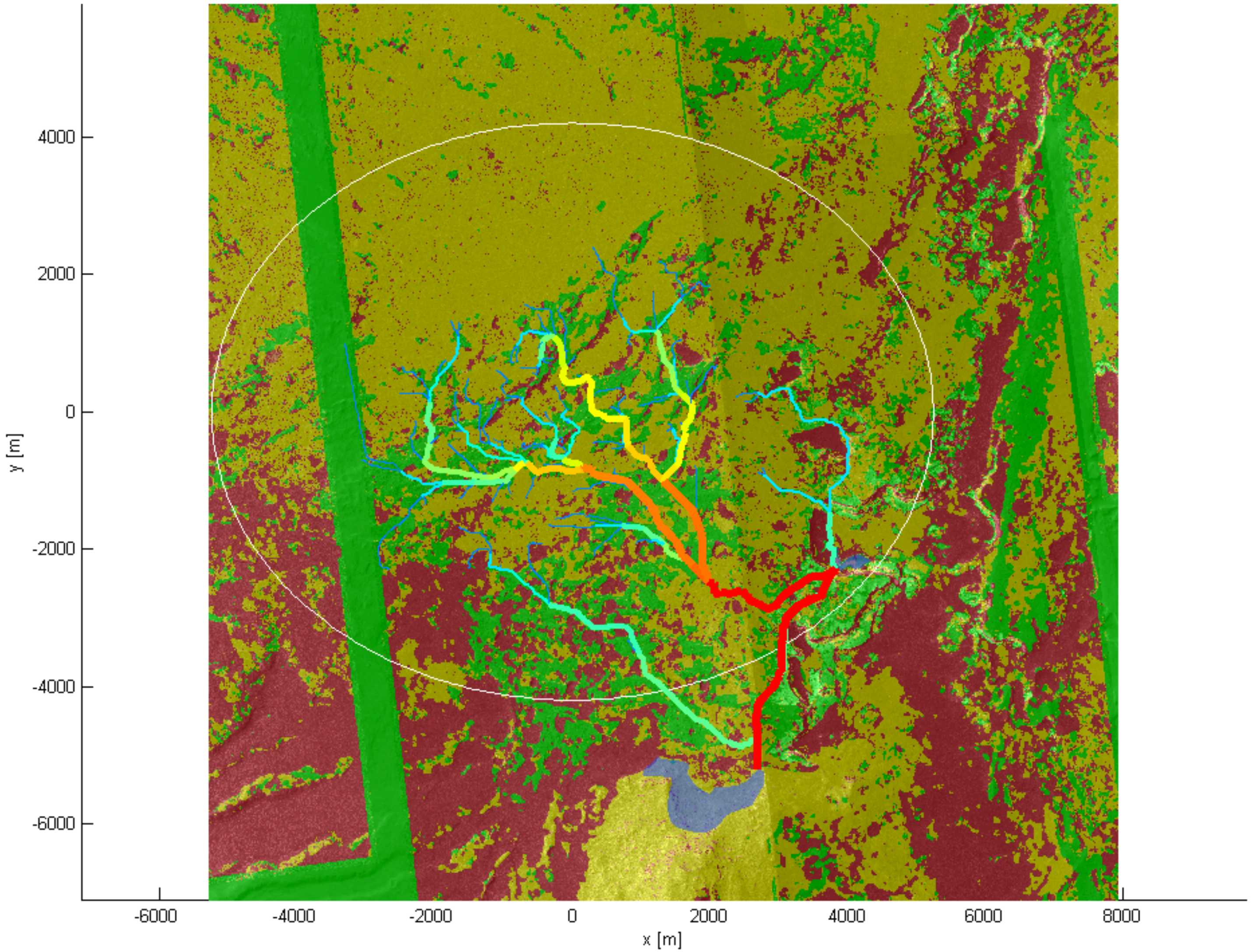
California Institute of Technology



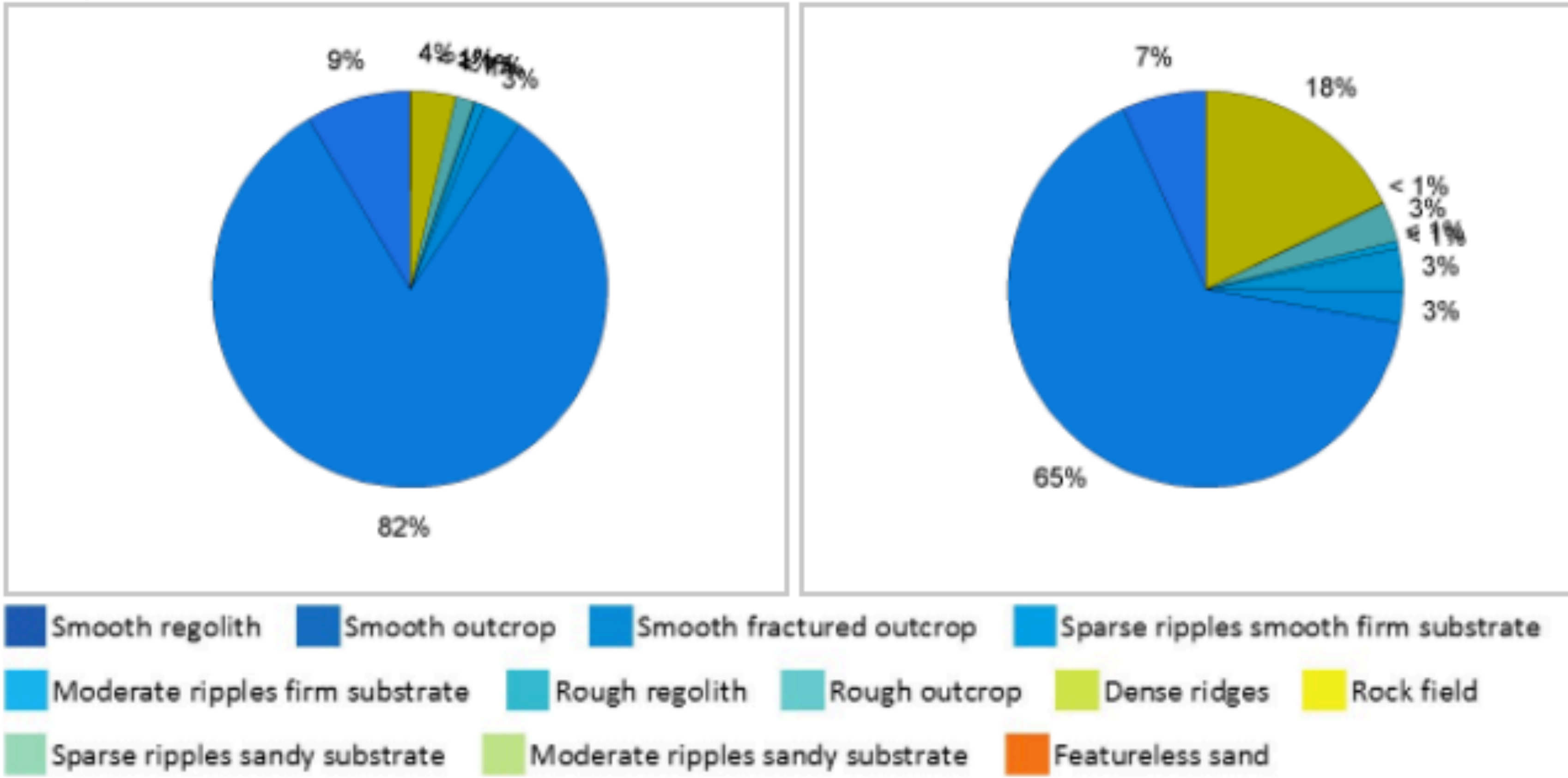

4000
2000
0
-2000
-4000
-6000
y [m]
-6000
-4000
-2000
0
2000
4000
6000
8000
x [m]

HOL Pie chart

Conservative

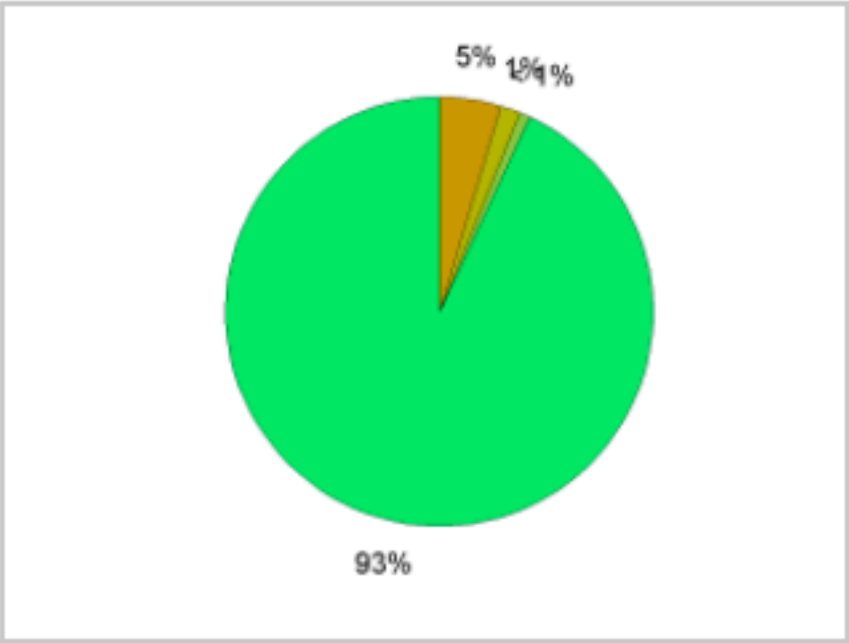
Average Distance: 10.2 km

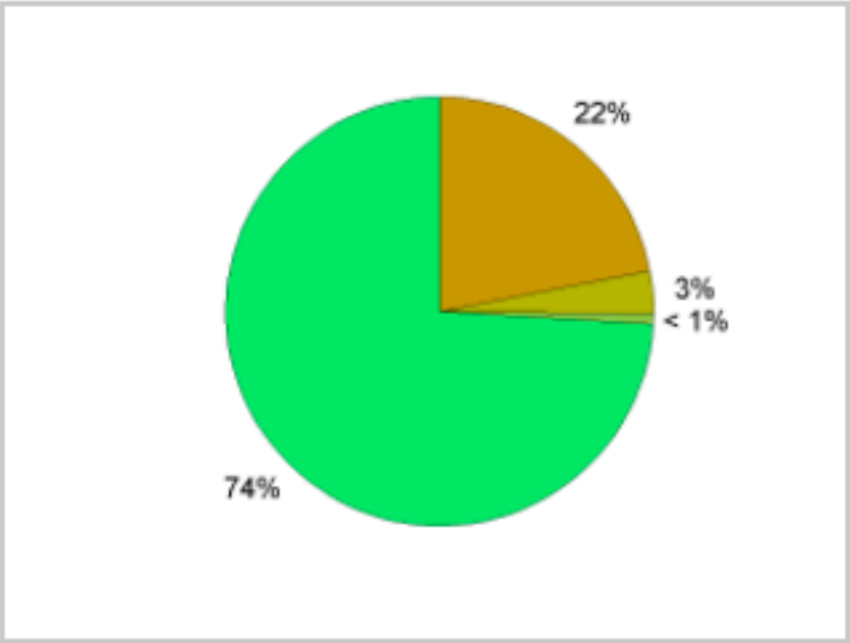
Average Time: 79.1 sols

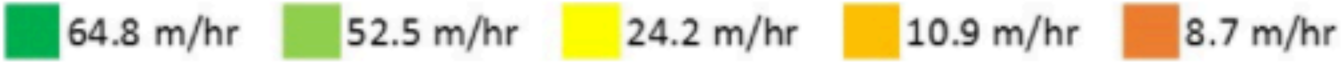


HOL Pie Chart

Conservative
Average Distance: 10.2 km
Average Time: 79.1 sols

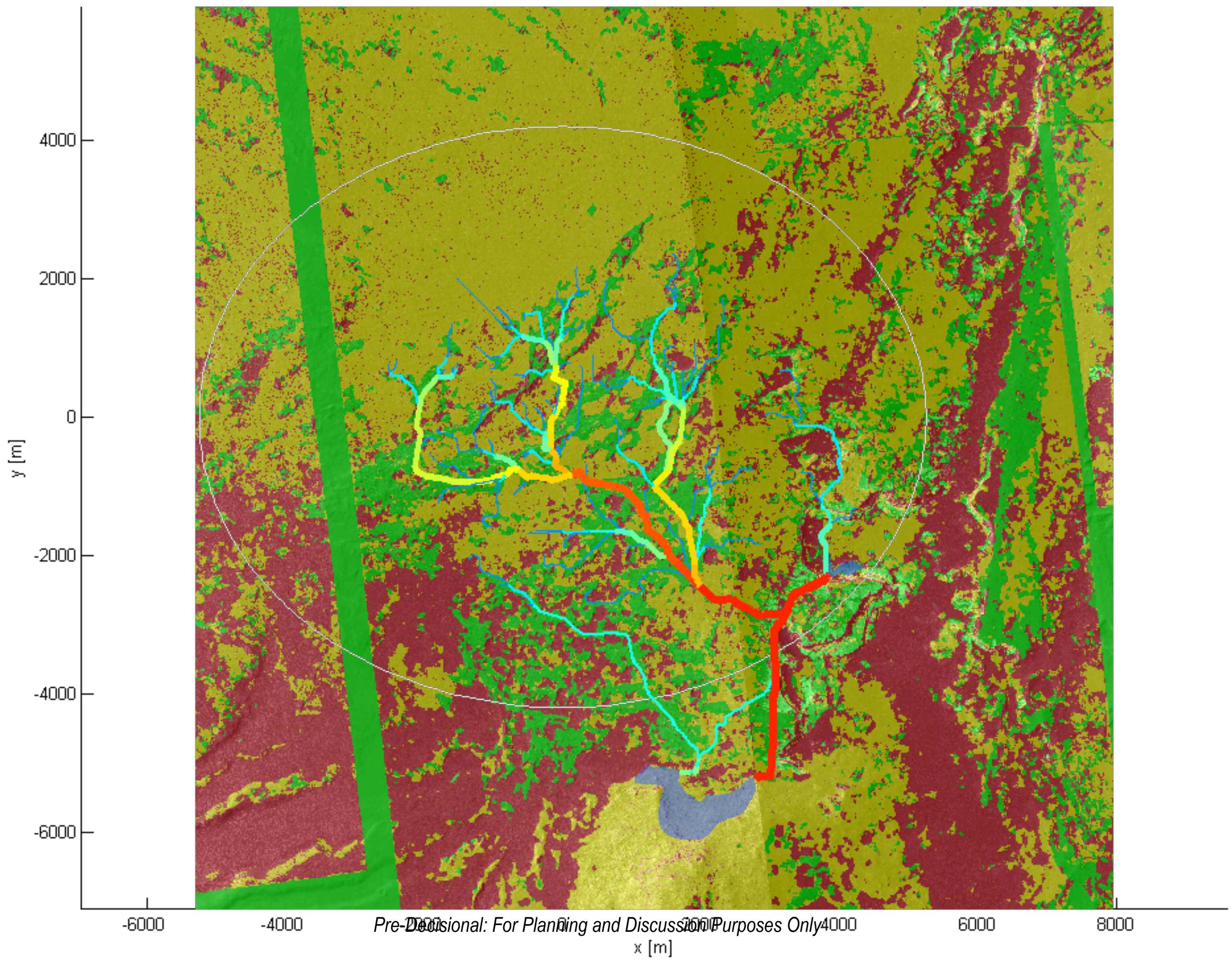






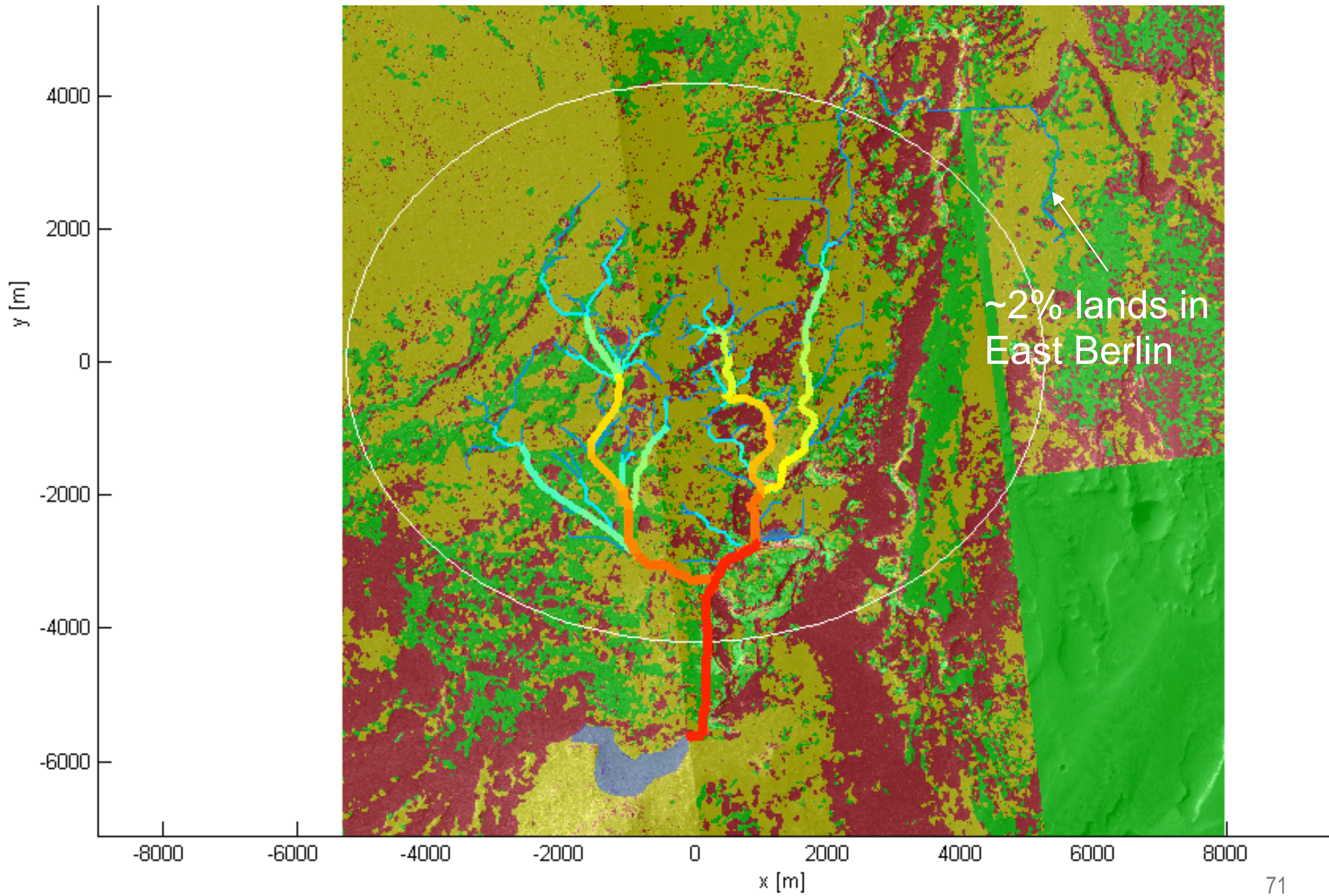
Original Ellipse

With conservative driving rate



East Ellipse

With conservative driving rate



Result: Distance

Original Ellipse

Drive rate assumption	50%	80%	85%	90%	95%
Optimistic	9.2 km	10.4 km	10.7 km	11.0 km	11.4 km
Conservative	10.3 km	11.8 km	12.2 km	12.6 km	13.3 km

East Ellipse

Drive rate assumption	50%	80%	85%	90%	95%
Optimistic	7.4 km	8.6 km	8.8 km	9.2 km	9.8 km
Conservative	8.7 km	10.6 km	11.0 km	11.6 km	12.6 km

8% Reduction in 90th percentile distance

Result: Time

Original Ellipse

Drive rate assumption	50%	80%	85%	90%	95%
Optimistic	60.8 sols	70.0 sols	71.9 sols	74.5 sols	78.5 sols
Conservative	80.0 sols	95.8 sols	100.0 sols	104.2 sols	115.8 sols

East Ellipse

Drive rate assumption	50%	80%	85%	90%	95%
Optimistic	51.9 sols	60.0 sols	61.5 sols	65.2 sols	69.6 sols
Conservative	74.4 sols	88.8 sols	94.8 sols	100.7 sols	116.3 sols

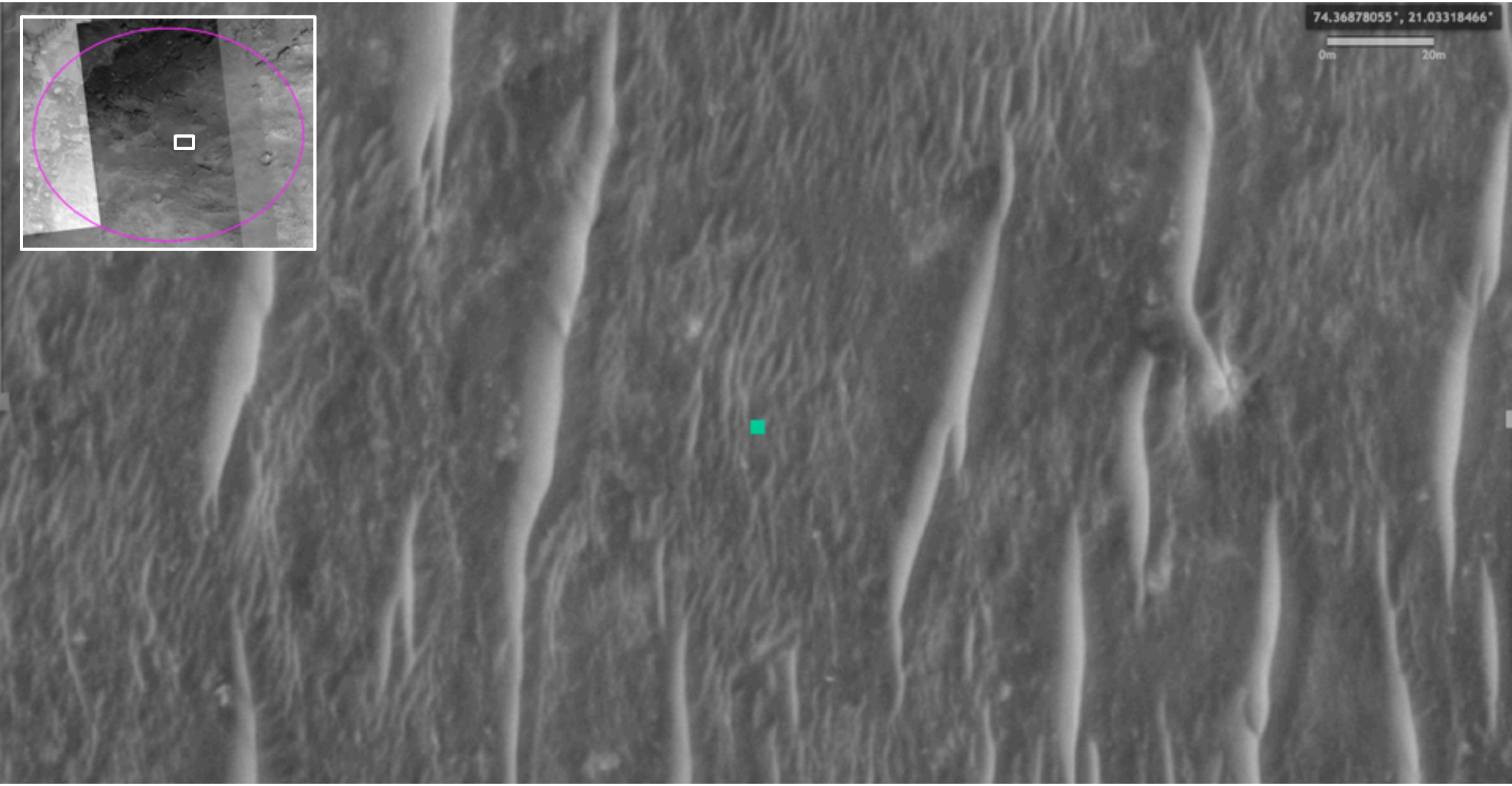
3.3% Reduction in 90^{th} percentile time

NIL

Key Challenges

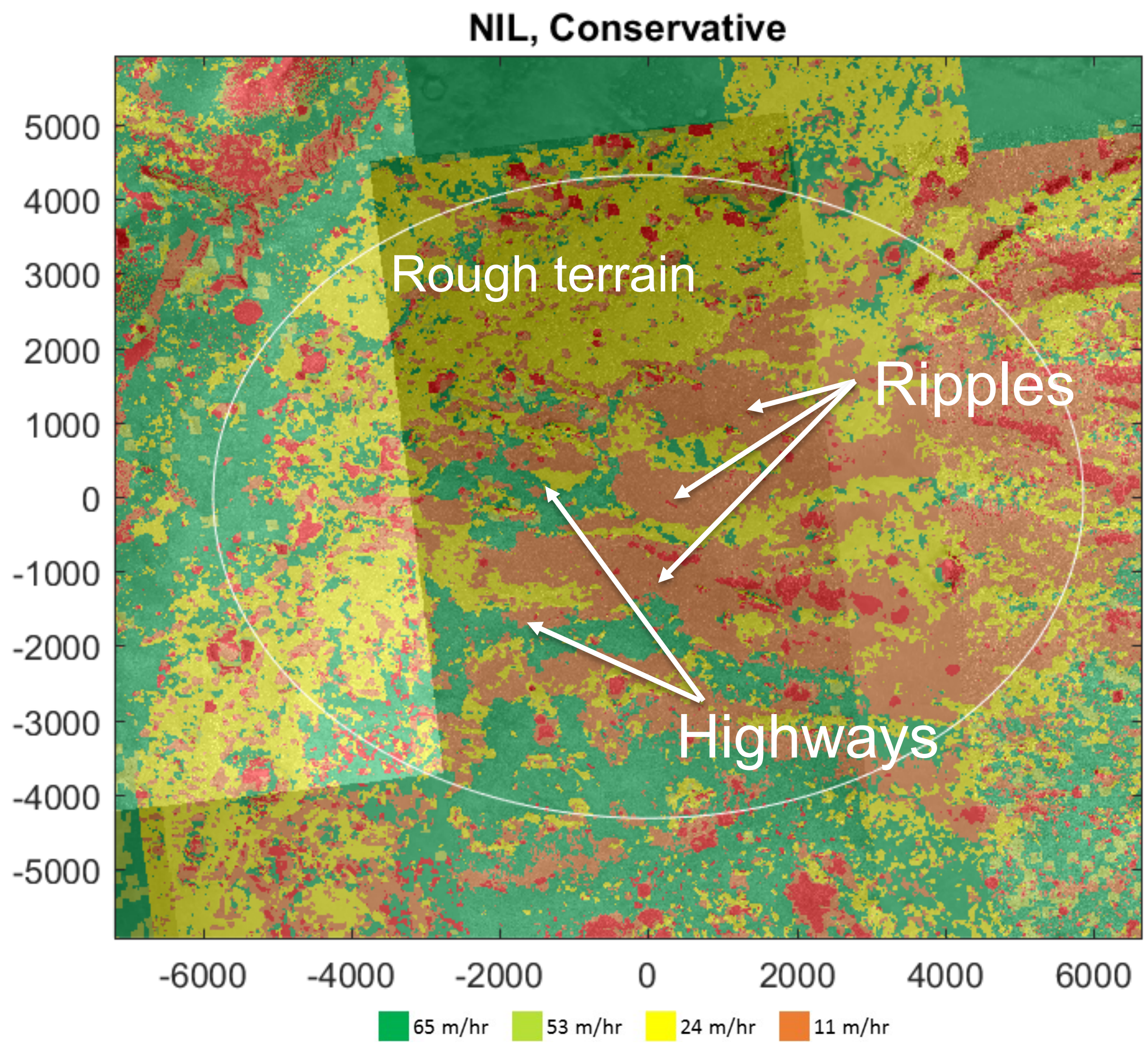
Often between the larger ripples there are smaller ripples which may cause traversability challenges. Not necessarily embedding hazards, but may cause high slip or cause trouble for AutoNav due to lack of texture

Map link



Traversability Map

Jet Propulsion Laboratory
California Institute of Technology



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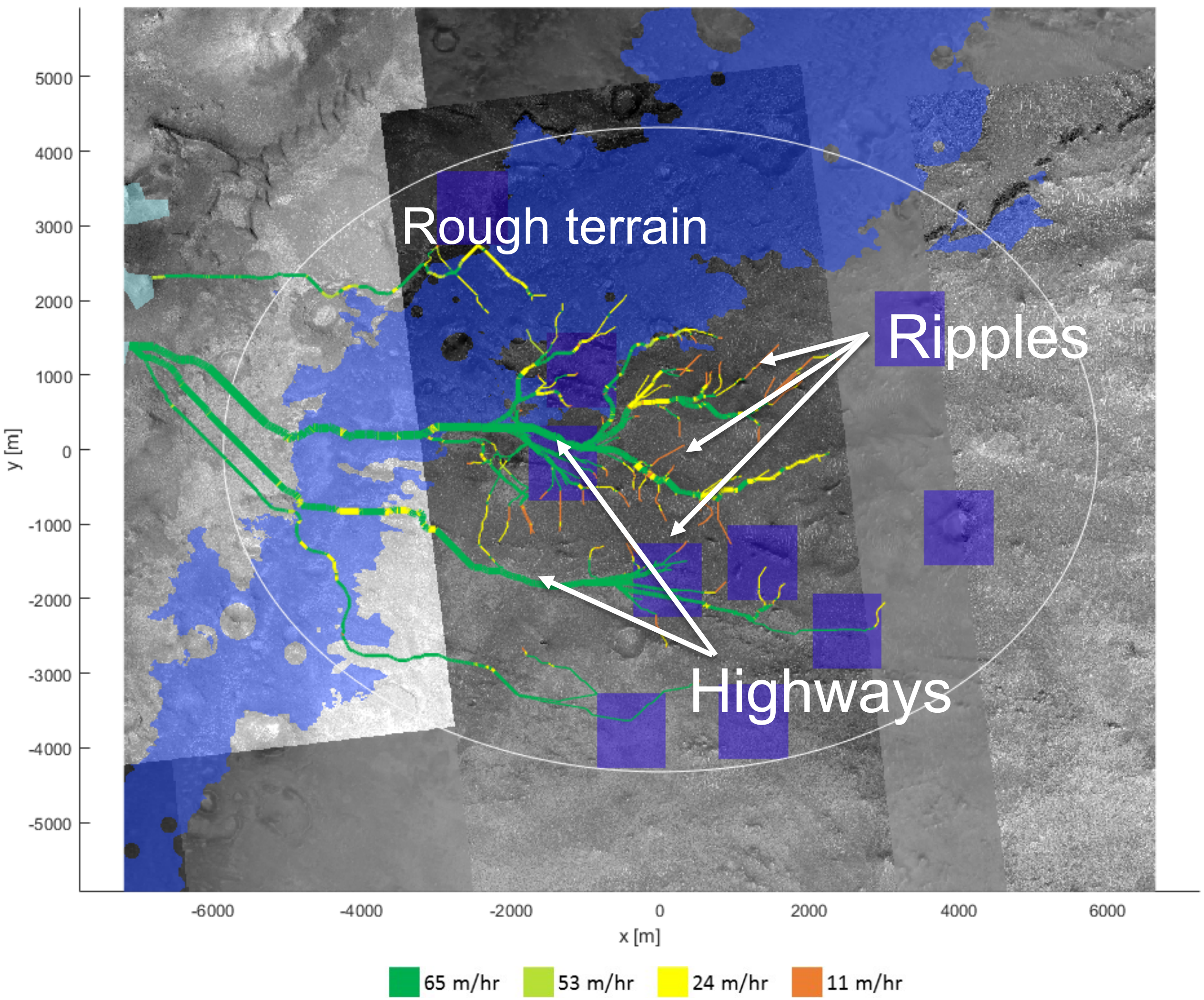
Traversability Map



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CLH

Key Challenges

CLH

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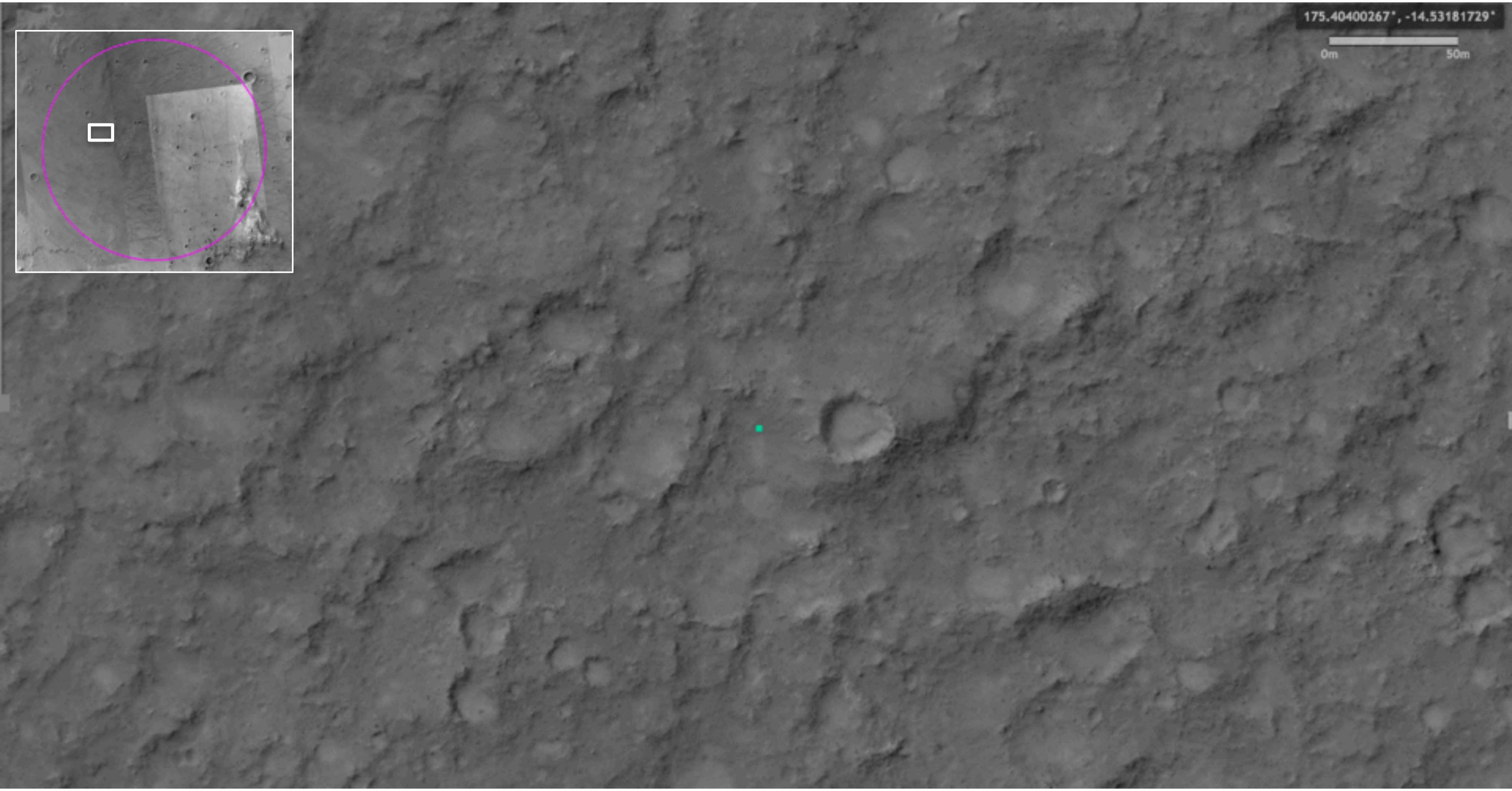
Mars 2020 Project

Many areas with undulating terrain that may affect viewshed and may require longer traverse routes.

Map link



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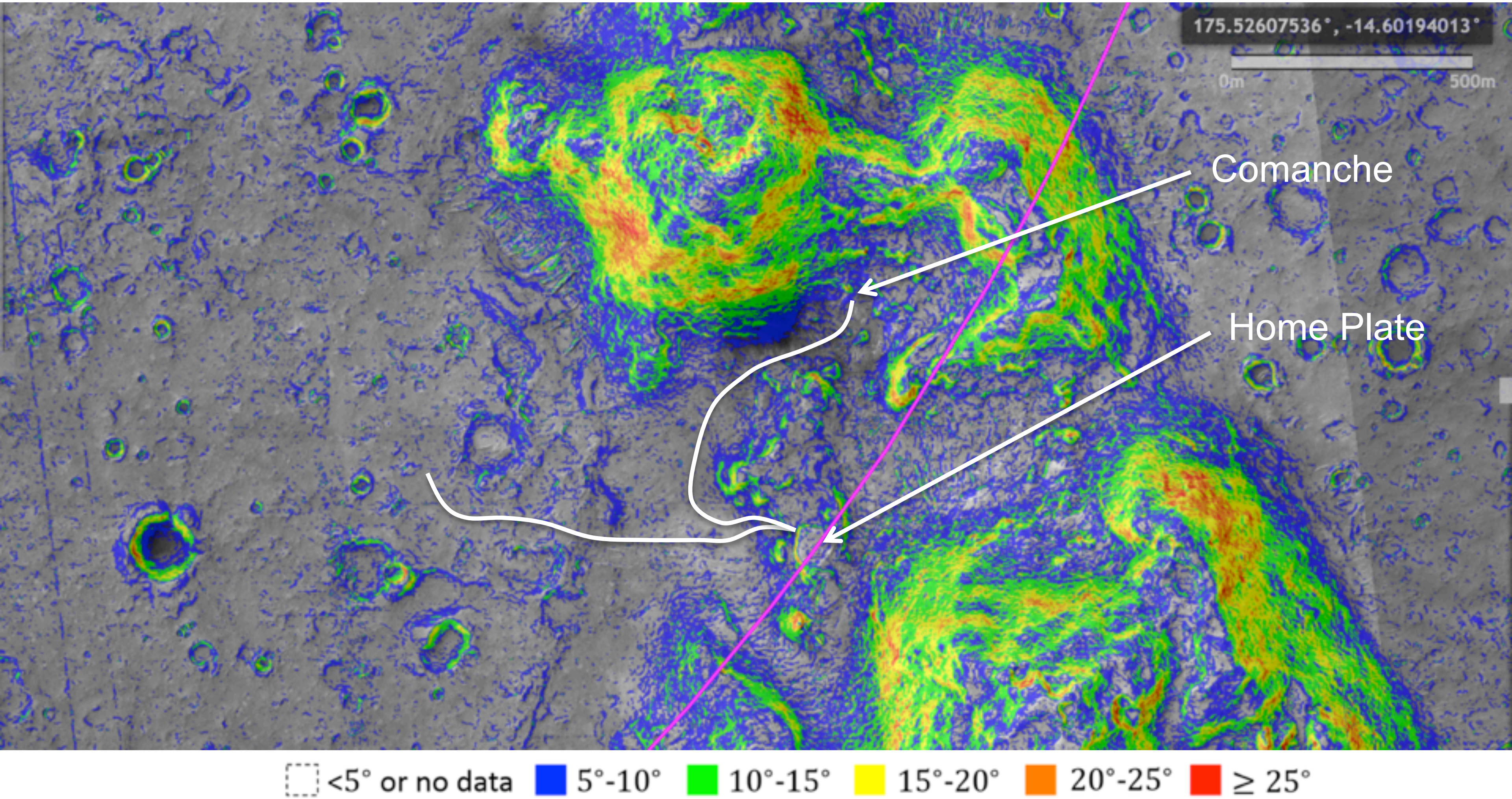
California Institute of Technology

Mars 2020 Project

Through the Columbia Hills

ROIs are easily reachable without the need to traverse over significant slopes at the Columbia Hills



Example routes shown for illustrative purposes only

EBW

Key Challenges

EBW

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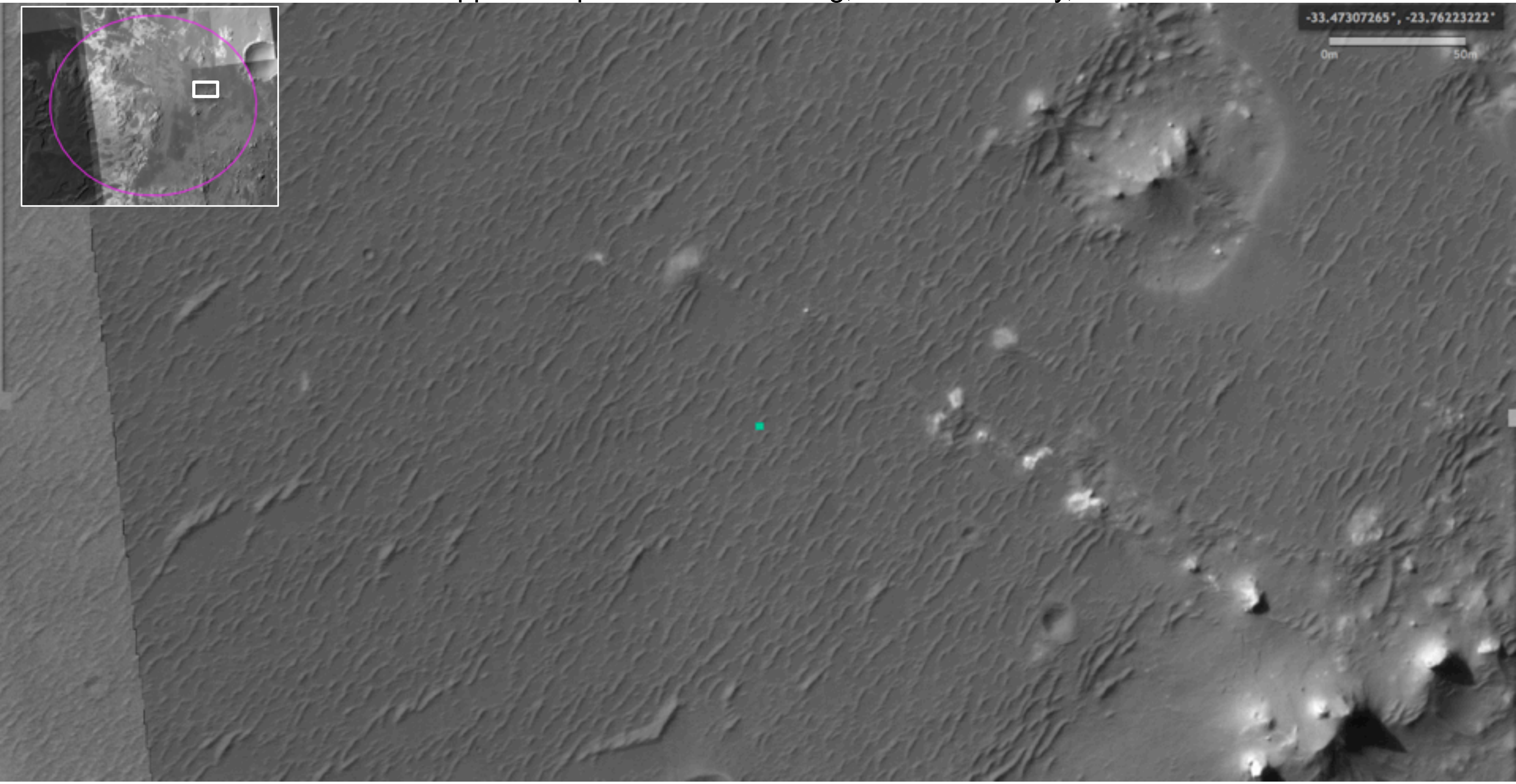
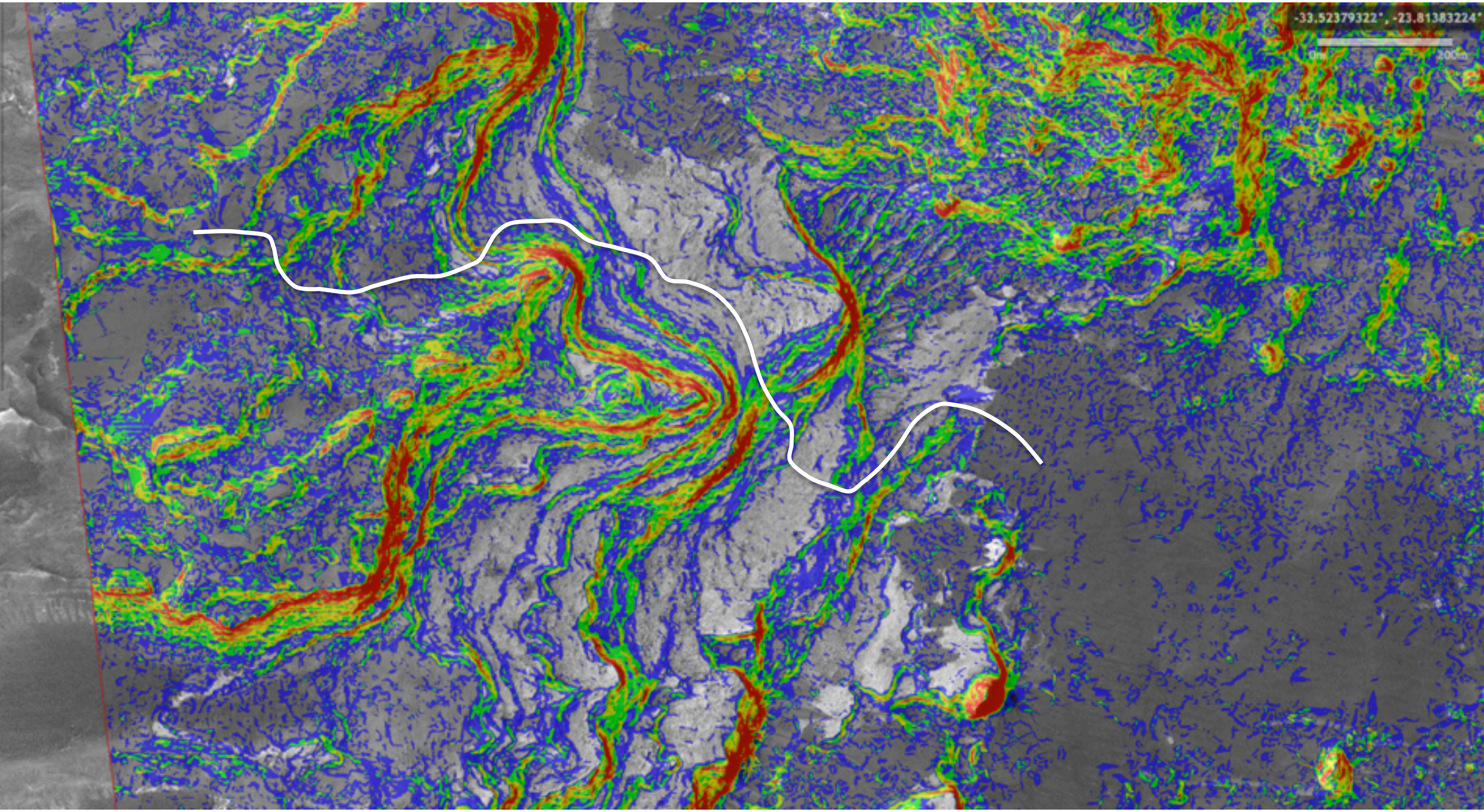
“Mantling unit” which is found throughout the terrain is flat and rock free, but it is covered with sand and small ripples. Appears traversable, but uncertain about the rate of progress due to lack of texture for stereo in sand and occlusions due to ripples. Impacts to blind driving, visual odometry, and AutoNav. Map link



Driving on and off the Delta

Map link



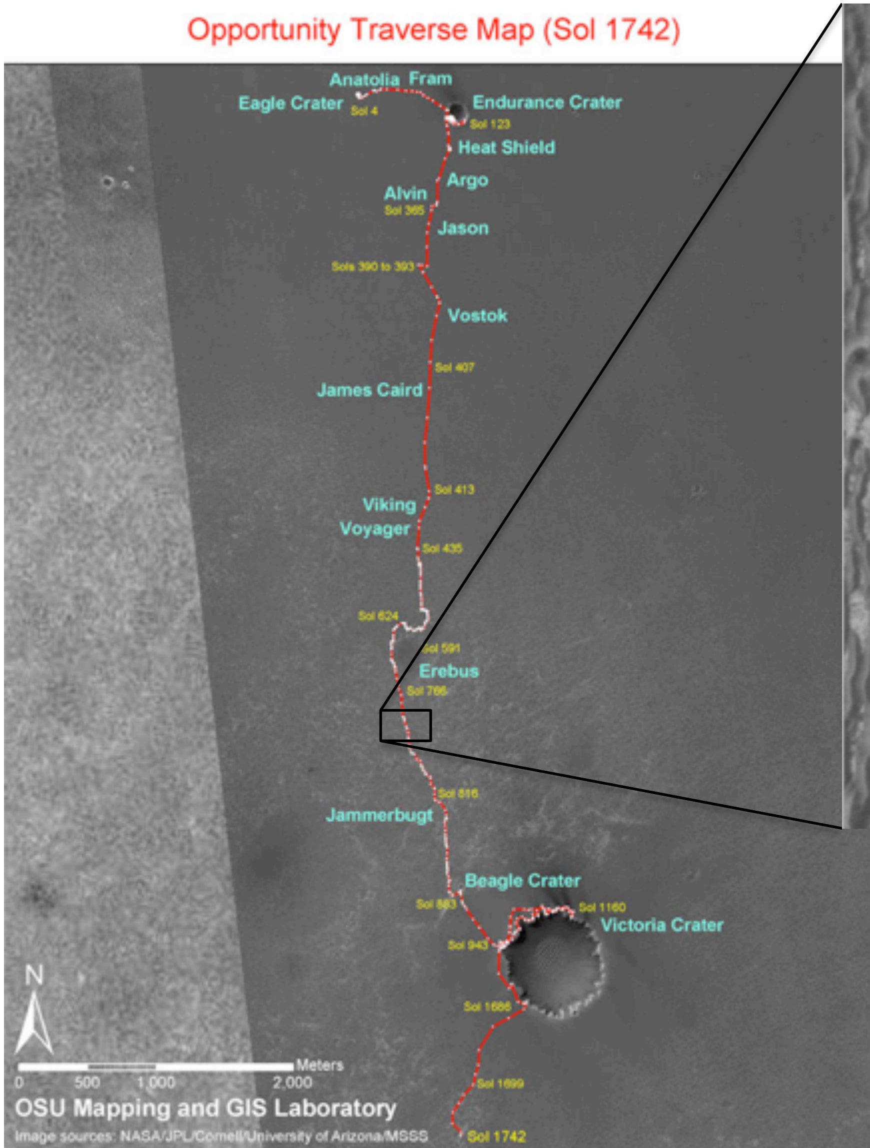
<5° or no data | 5°-10° | 10°-15° | 15°-20° | 20°-25° | ≥ 25°

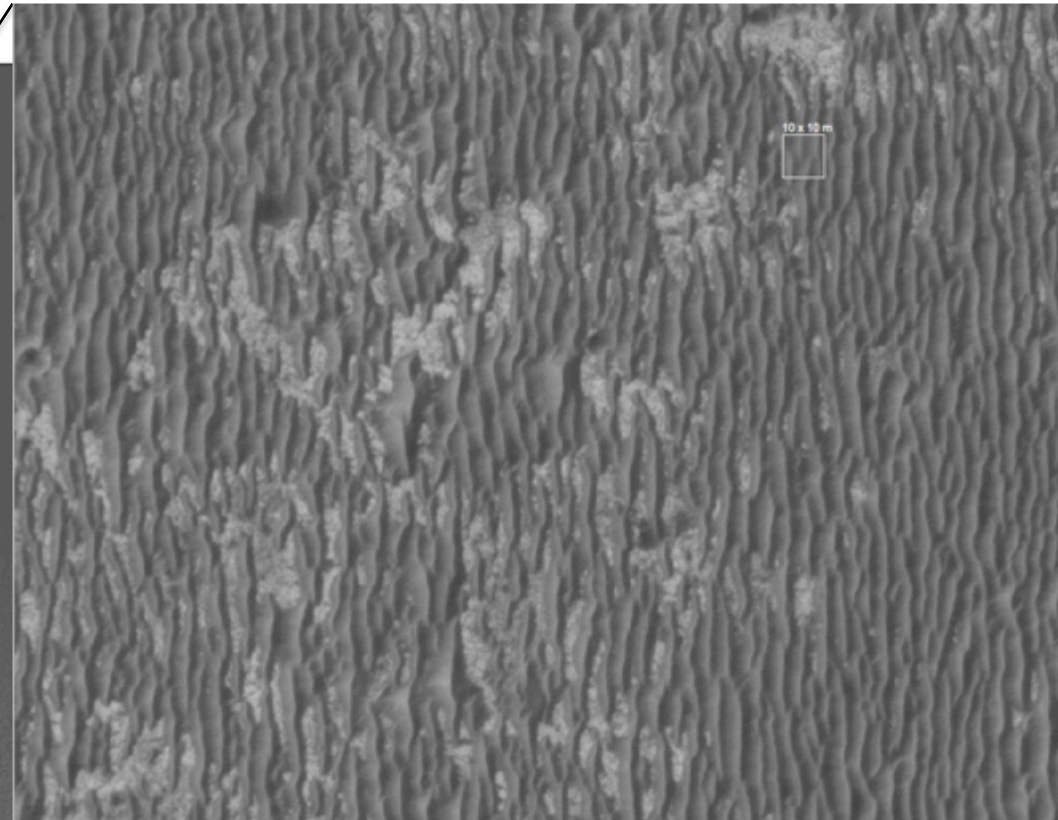
JEZ

Basin Fill

Map link

Similar to Terrain Seen by Opportunity





Sparse linear ripple field

Firm terrain between ripples

Opportunity Ripples

Opportunity sol 795

Not the easiest of driving, but no danger to the vehicle

JEZ Key Challenges

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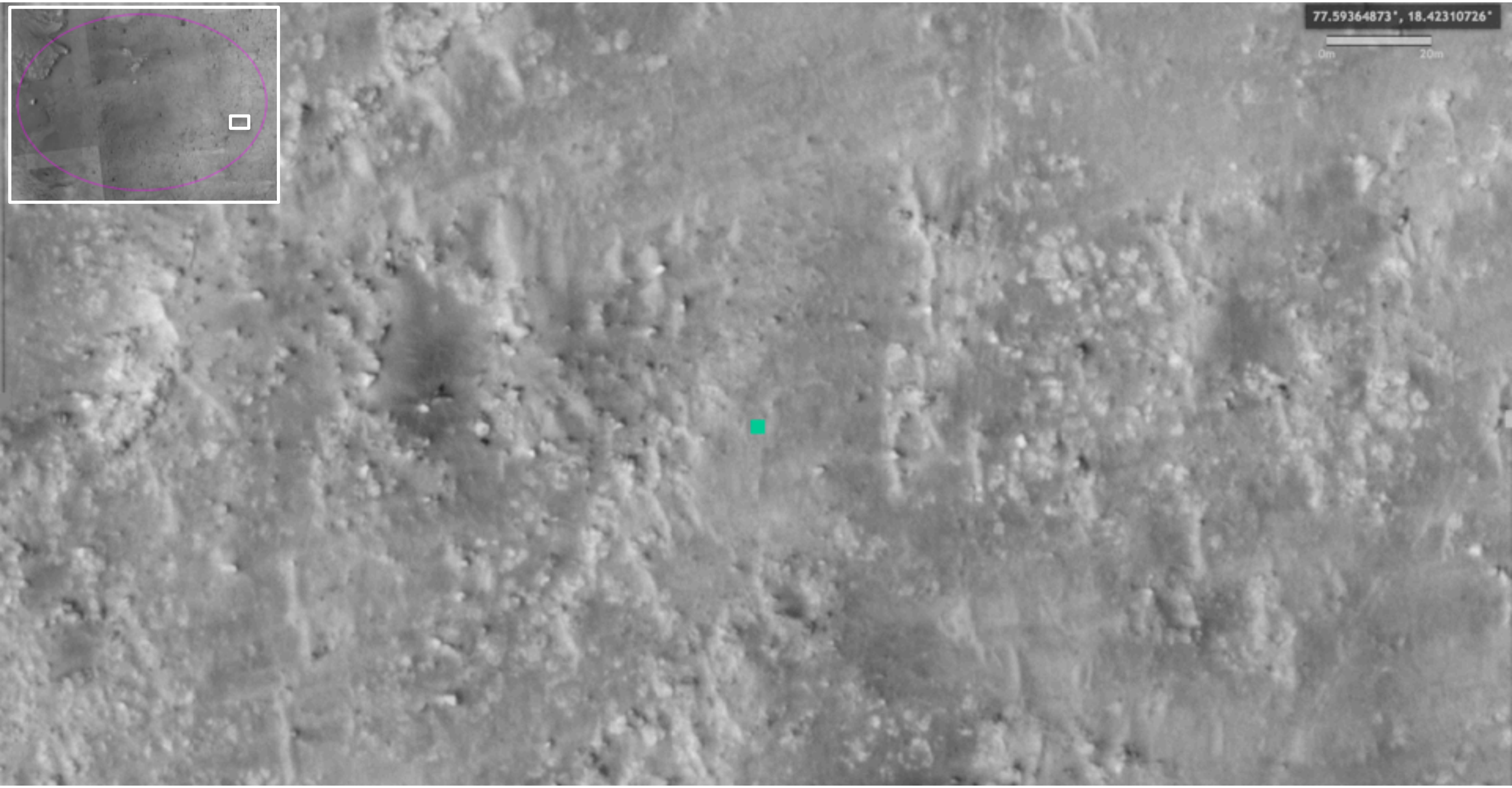
The eastern portion of the ellipse has a high abundance of rocks

Map link



MAW

Key Challenges

MAW

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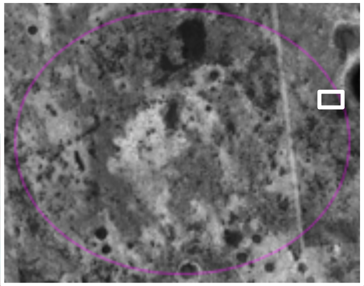
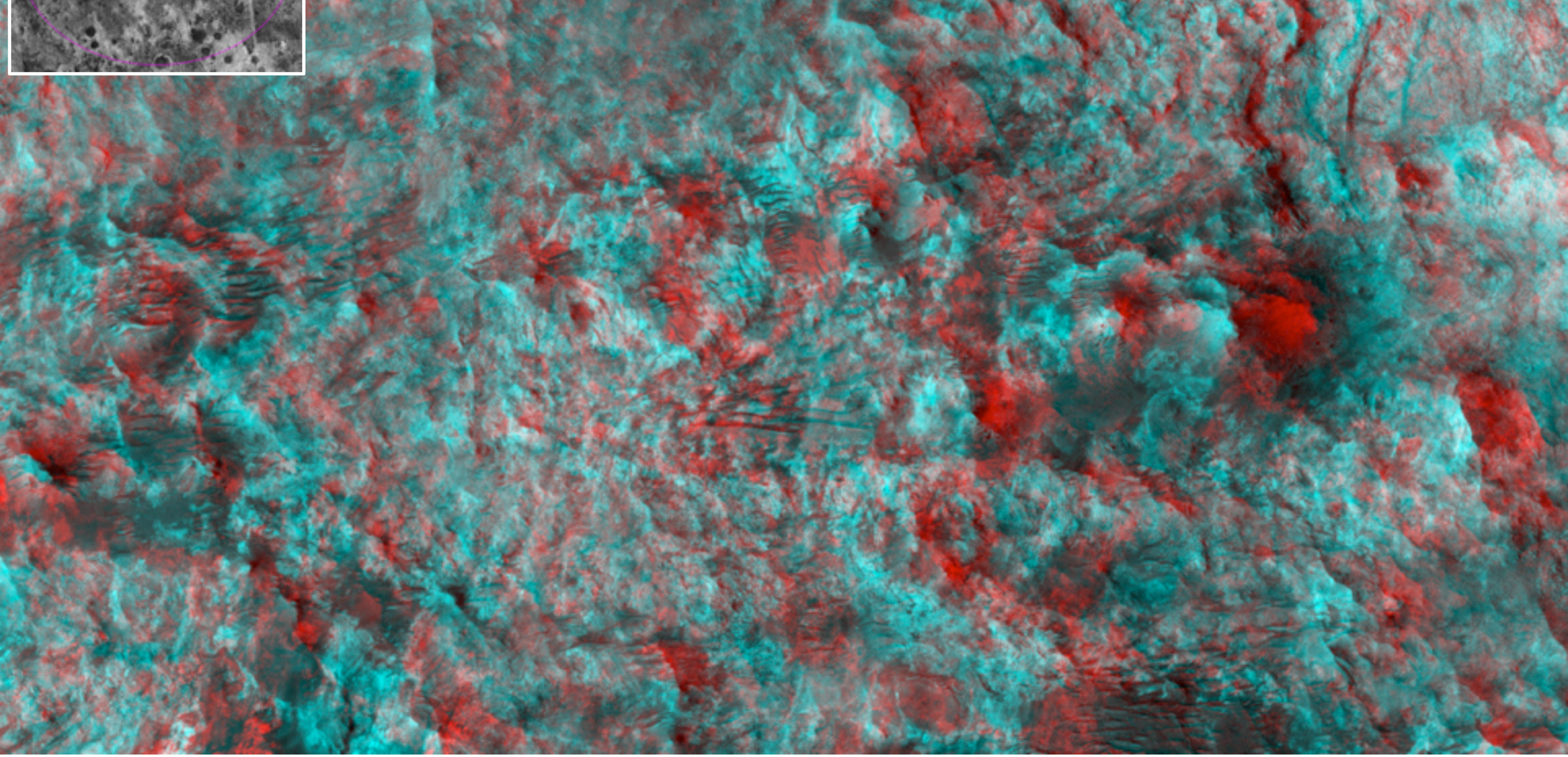


Rougher terrain, which means slower driving and more challenging for AutoNav, near the perimeter of the ellipse.



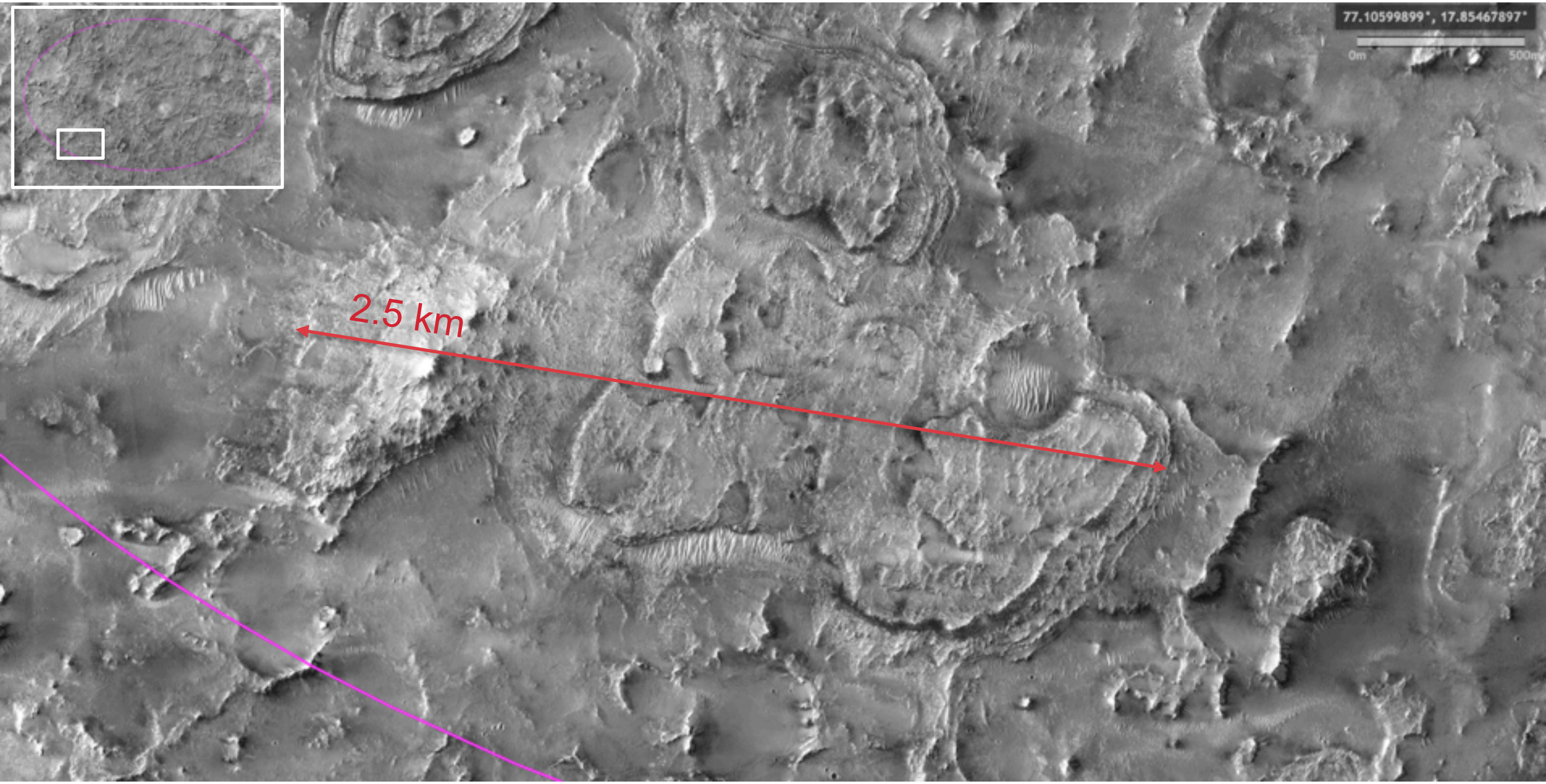
Source image PSP_005964_2045

NES

Key Challenges

Some large scale challenging terrain features that would require many kilometers to avoid. These areas are often categorized as ROIs

Map link

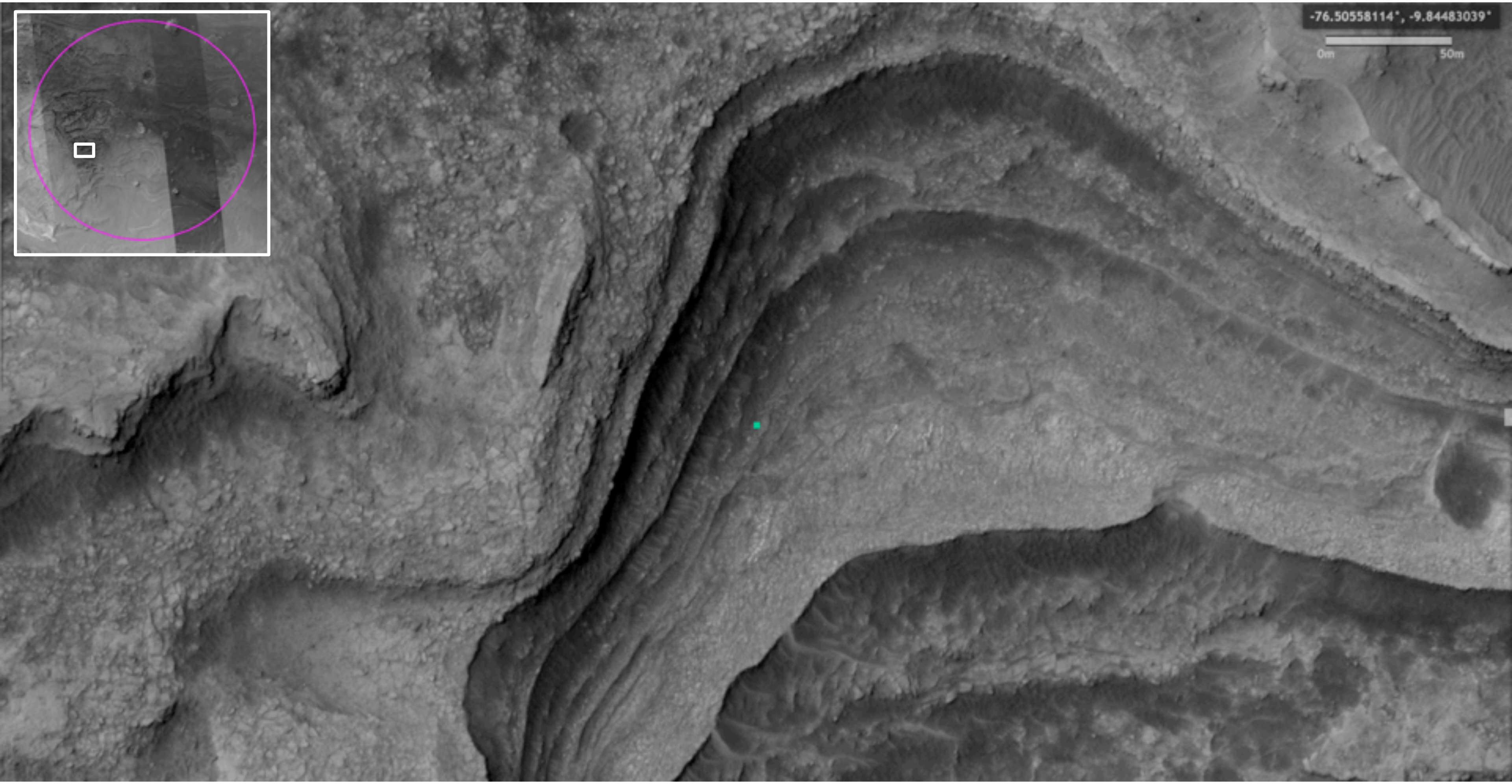


SWM

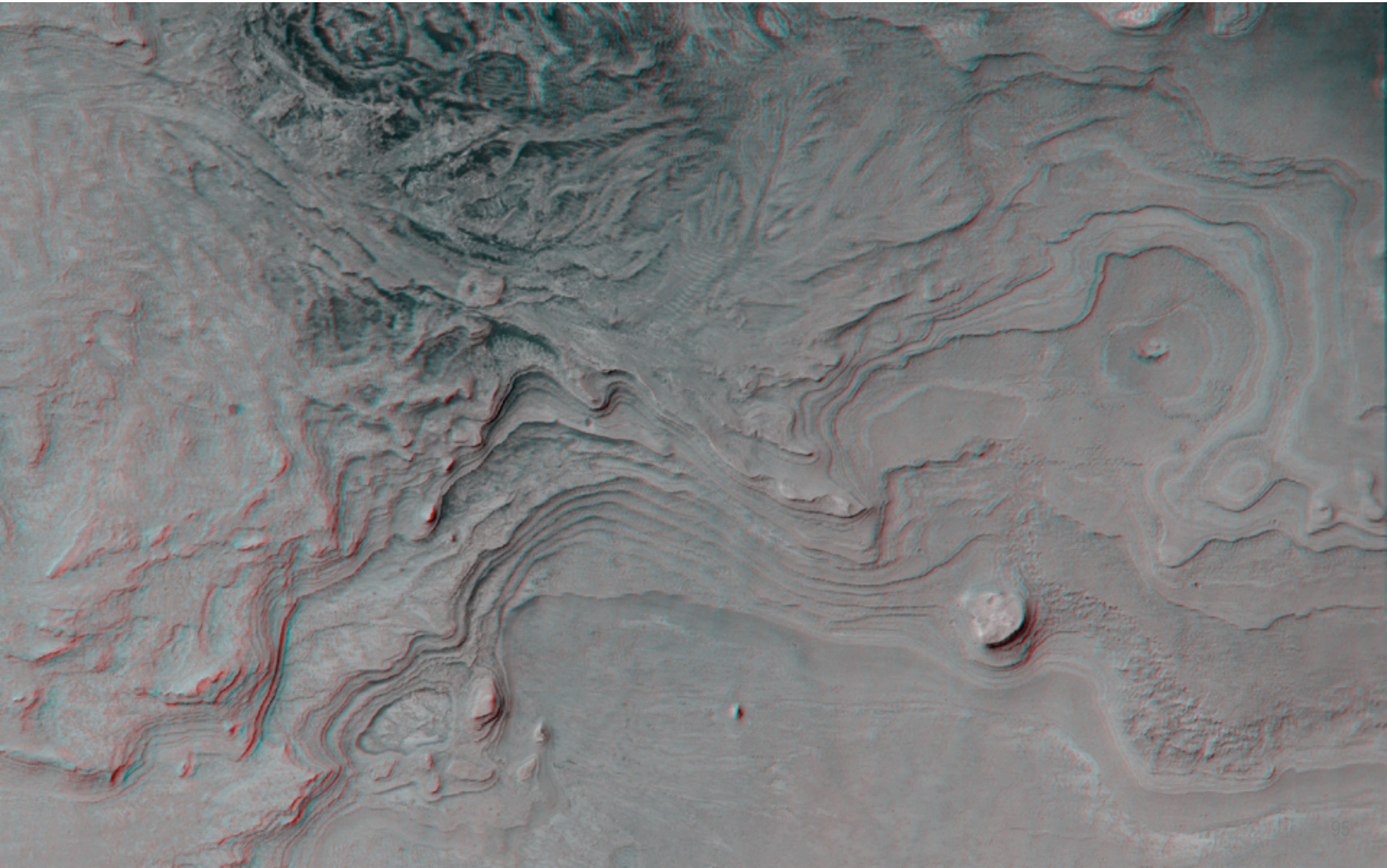
Key Challenges

Many steep scarps and lots of rough outcrop which makes for slow and challenging driving.

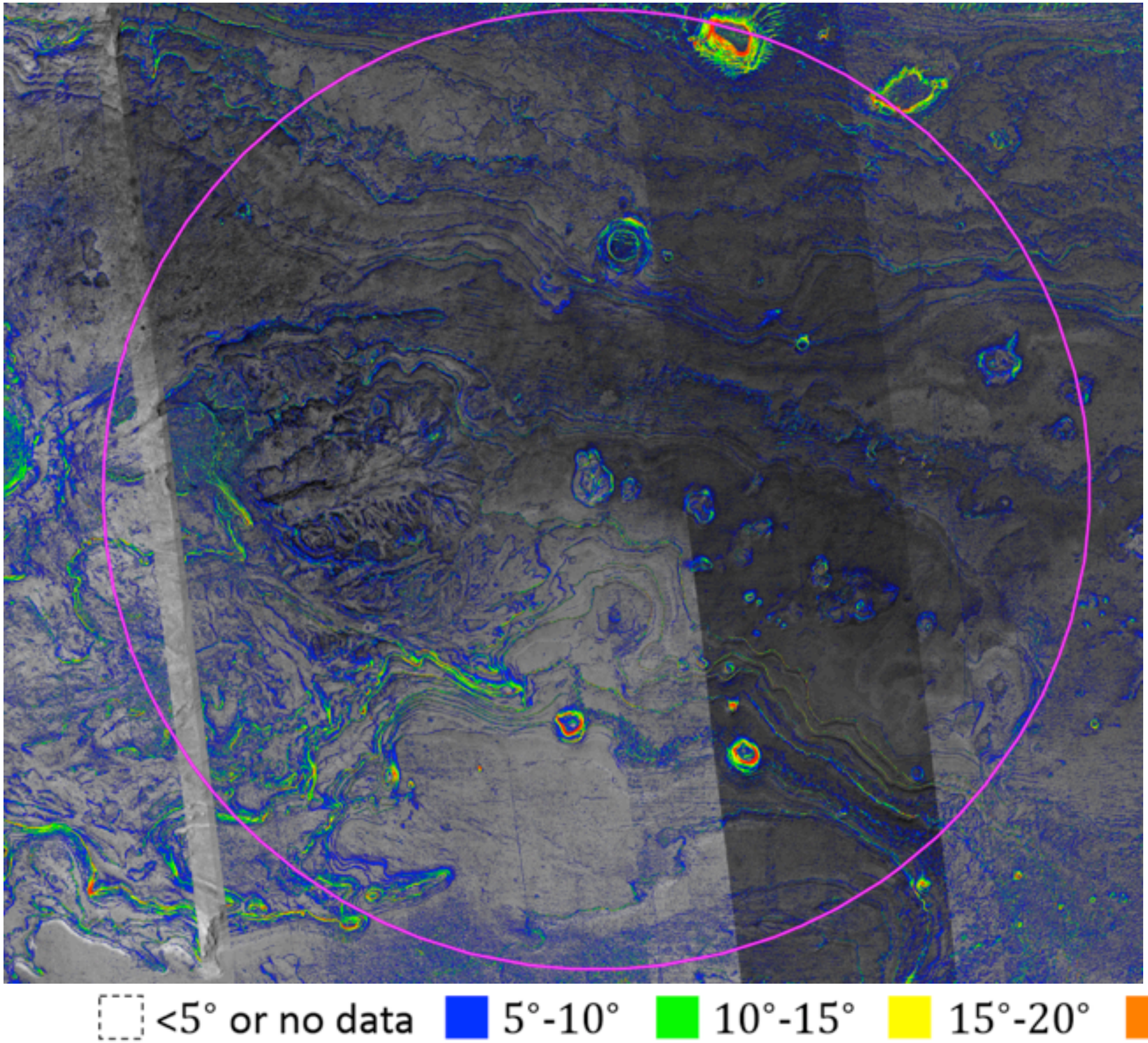
Map link



Key Challenge



Slopes

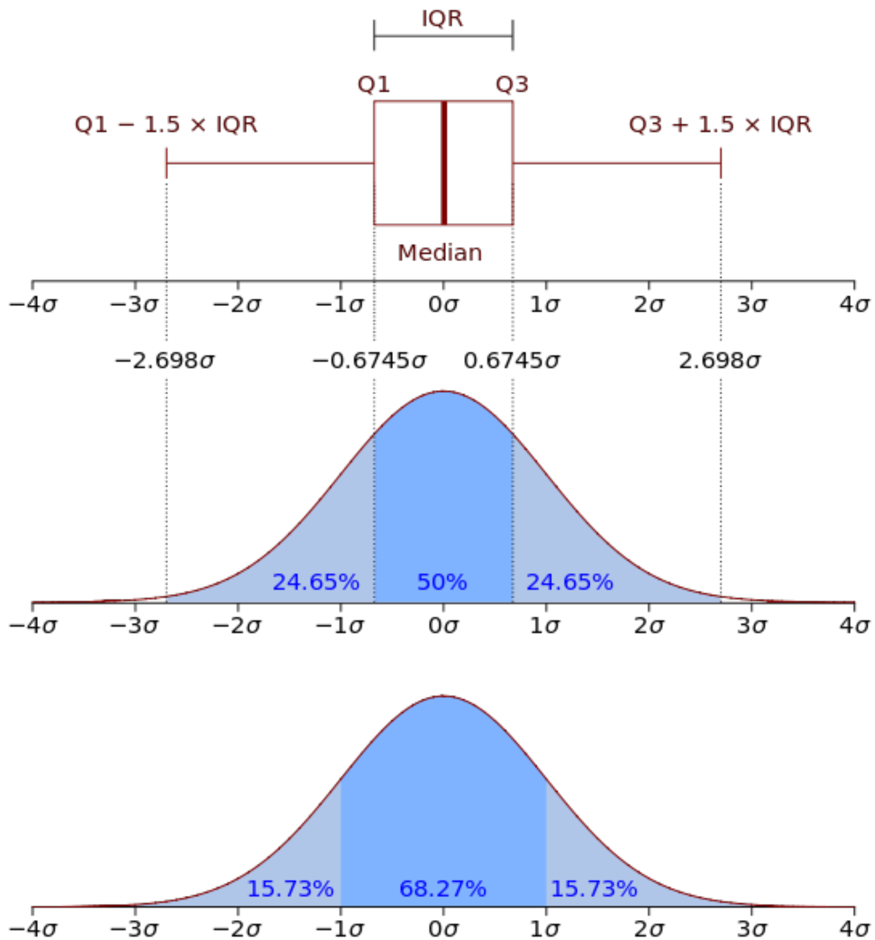


Slope calculation algorithm may not accurately capture the traversability of wheel diameter sized scarps, which may be challenging for ascent.

Qualitative analysis makes us believe that there are viable routes up the ledges, but the traverse distance analysis may not accurately reflect the circuitous route likely needed to find a viable ascent path.

Backup Slides

How to read a box plot



Graphic borrowed from Wikipedia
https://en.wikipedia.org/wiki/File:Boxplot_vs_PDF.svg

Landing Site Tour

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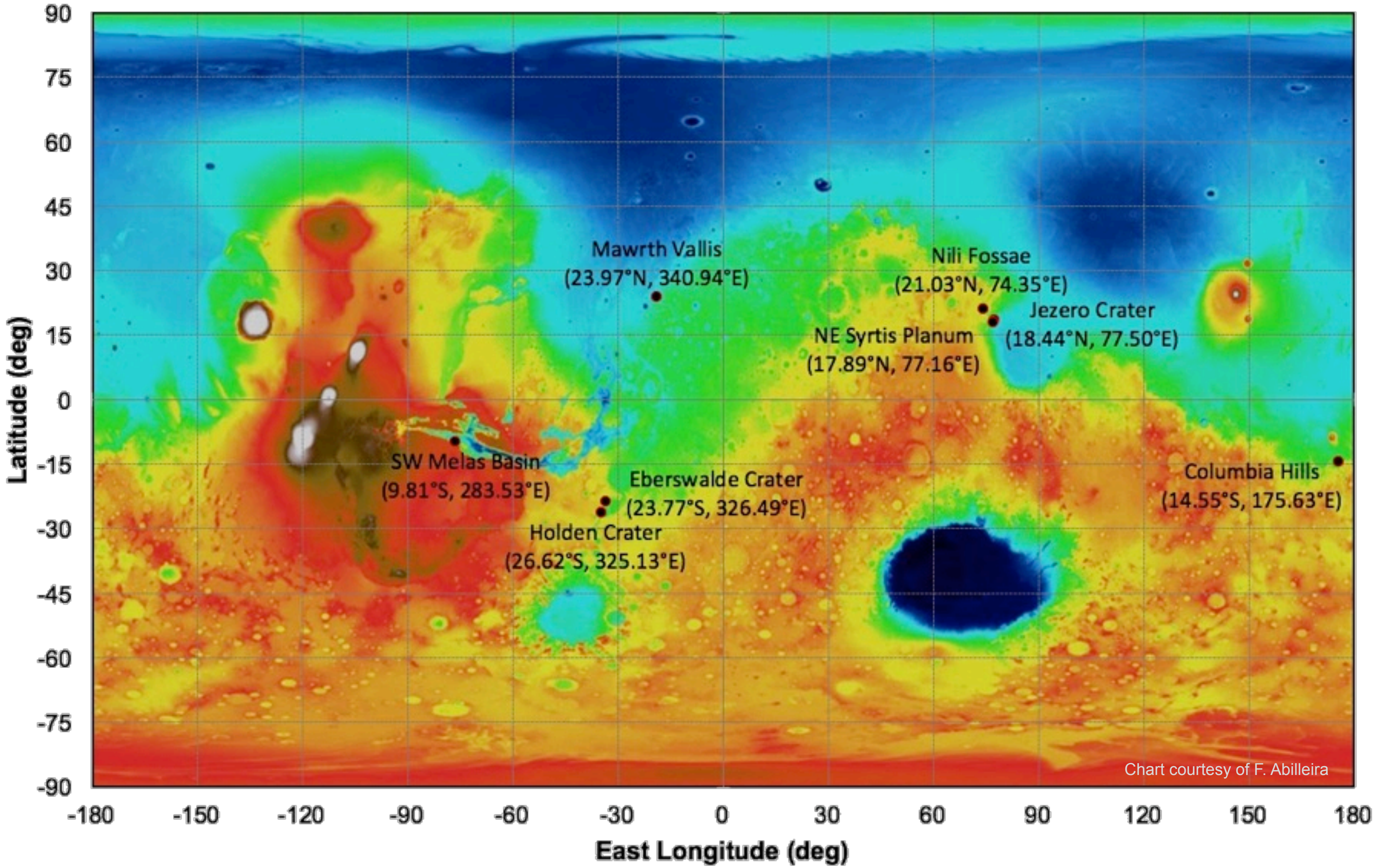

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